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10	40	(lip or rim) same injection same (mold or mould or molding or moulding or molded or moulded) same (second)	EPO; JPO	2003/02/11 13:29
11	1	(lip or rim) same injection same (mold or mould or molding or moulding or molded or moulded) and (flower or planter)	EPO; JPO	2003/02/11 13:39
12	262	((47/65.5) or (47/66.1)).CCLS.	USPAT; US-PGPUB	2003/02/11 13:40

Lehman, Karen

From: Gellner, Jeffrey
Sent: Tuesday, February 11, 2003 2:02 PM
To: Lehman, Karen
Subject: 10/062303

Hi Karen,

Could you please get the definitions of "blow molding" and "injection molding" and some kind of comparision between the two as to when used, strengths, etc.

Thanks.

Jeff G.

processing methods

Injection Molding
Injection molding is the principal method of forming thermoplastic materials. Modifications of the injection process are sometimes used for thermosetting plastics.

In injection molding, plastic material is put into a hopper which feeds into a heated injection unit. A reciprocating screw pushes the plastic through this long heating chamber, where the material is softened to a fluid state. At the end of this chamber there is a nozzle which abuts firmly against an opening into a cool, closed mold. The fluid plastic is forced at high pressure through this nozzle into the cold mold. A system of clamps hold the mold halves shut. As soon as the plastic cools to a solid state, the mold opens and the finished plastic is ejected from the press.

The problem with injection molding of thermosetting materials is that, under heat, these plastics will first soften, then harden to an infusible state. Thus it is essential that no softened thermosetting material in the heating chamber be allowed to remain there long enough to set. Jet molding, offset molding and molding using a screw-type machine overcome this problem by liquefying the thermosetting plastic material just as it goes through the injection nozzle into the mold, but not before. Search SPI's Membership Directory & Buyer's Guide for injection molders.

Blow Molding
Blow molding is a method of forming hollow articles out of thermoplastic materials.

Blow molding is a process of forming a molten tube of thermoplastic material, then with the use of compressed air, blowing up the tube to conform to the interior of a chilled blow mold. The most common methods are extrusion, injection, and injection-stretch blow molding.

The continuous-extrusion method uses a continuously running extruder with a tuned die head that forms the molten plastic tube. The tube is then pinched between two mold halves. A blow pin or needle is inserted into the tube and compressed air is used to blow up the part to conform to the chilled mold interior. Accumulator-extrusion is similar, however, the molten plastic material is accumulated in a chamber prior to being forced through a die to form the tube.

Injection blow molding is a process of injection molding a preform (similar to a test tube), then taking the tempered preform to a blow mold to be filled with compressed air to conform to the interior of the blow mold. Injection-stretch blow molding can be a single-stage process similar to standard injection blow molding, by adding the element of stretch prior to blow forming. Also, a two-step process is possible, where a preform is made in an injection molding machine, then taken to a reheat-stretch blow molding machine for preform reheating and final blow forming in a blow mold. Search SPI's Membership Directory & Buyer's Guide for blow molders.

Thermoforming
Thermoforming of plastic sheet has developed rapidly in recent years. This process consists of heating thermoplastic sheet to a formable plastic state and then applying air and/or mechanical assists to shape it to the contours of a mold.

Air pressure may range from almost zero to several hundred psi. Up to approximately 14 psi (atmospheric pressure), the pressure is obtained by evacuating the space between the sheet and the mold in order to utilize this atmospheric pressure. This range, known as vacuum forming, will give satisfactory reproduction of the mold configuration in the majority of forming applications. Search SPI's Membership Directory & Buyer's Guide for thermoformers.

Transfer Molding

Transfer molding is most generally used for thermosetting plastics. This method is like compression molding in that the plastic is cured into an infusible state in a mold under heat and pressure. It differs from compression molding in that the plastic is heated to a point of plasticity before it reaches the mold and is forced into a closed mold by means of a hydraulically operated plunger.

Transfer molding was developed to facilitate the molding of intricate products with small deep holes or numerous metal inserts. The dry mold compound used in compression molding sometimes disturbs the position of the metal inserts and the pins which form the holes. The liquefied plastic material in transfer molding flows around these metal parts without causing them to shift position. Search SPI's Membership Directory & Buyer's Guide for transfer molders.

Reaction Injection Molding

Reaction injection molding (RIM) is a relatively new processing technique that has rapidly taken its place alongside more traditional methods. Unlike liquid casting, the two liquid components, polyols and isocyanates, are mixed in a chamber at relatively low temperatures (75° - 140° F) before being injected into a closed mold. An exothermic reaction occurs, and consequently RIM requires far less energy usage than any other injection molding system.

The three major types of polyurethane RIM systems are rigid structural foam, low-modulus elastomers, and high-modulus elastomers.

Reinforced RIM (R-RIM) consists of the addition of such materials as chopped or milled glass fiber to the polyurethane to enhance stiffness and to increase modulus, thus expanding the range of applications. Search SPI's Membership Directory & Buyer's Guide for RIM molders.

Compression Molding

Compression molding is the most common method of forming thermosetting materials. It is not generally used for thermoplastics.

Compression molding is simply the squeezing of a material into a desired shape by application of heat and pressure to the material in a mold.

Plastic molding powder, mixed with such materials or fillers as woodflour and cellulose to strengthen or give other added qualities to the finished product, is put directly into the open mold cavity. The mold is then closed, pressing down on the plastic and causing it to flow throughout the mold. It is while the heated mold is closed that the thermosetting material undergoes a chemical change which permanently hardens it into the shape of the mold. The three compression molding factors -- pressure, temperature and time the mold is closed -- vary with the design of the finished article and the material being molded. Search SPI's Membership Directory & Buyer's Guide for compression molders.

Extrusion

Extrusion molding is the method employed to form thermoplastic materials into continuous sheeting, film, tubes, rods, profile shapes, and filaments, and to coat wire, cable and cord.

In extrusion, dry plastic material is first loaded into a hopper, then fed into a long heating chamber through which it is moved by the action of a continuously revolving screw. At the end of the heating chamber the molten plastic is forced out through a small opening or die with the shape desired in

the finished product. As the plastic extrusion comes from the die, it is fed onto a conveyor belt where it is cooled, most frequently by blowers or by immersion in water.

In the case of wire and cable coating, the thermoplastic is extruded around a continuing length of wire or cable which, like the plastic, passes through the extruder die. The coated wire is wound on drums after cooling.

In the production of wide film or sheeting, the plastic is extruded in the form of a tube. This tube may be split as it comes from the die and then stretched and thinned to the dimensions desired in the finished film.

In a different process, the extruded tubing is inflated as it comes from the die, the degree of inflation of the tubing regulating the thickness of the final film. Search SPI's Membership Directory & Buyer's Guide for extruders.

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INJECTION

MOLDING

HANDBOOK

THIRD EDITION

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Kluwer Academic Publishers
Boston/Dordrecht/London

Distributors for North, Central and South America:
Kluwer Academic Publishers
101 Philip Drive
Assinippi Park
Norwell, Massachusetts 02061 USA
Telephone (781) 871-6600
Fax (781) 871-6528
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Distributors for all other countries:
Kluwer Academic Publishers Group
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Telephone 31 78 6392 392
Fax 31 78 6546 474
E-Mail <orderdept@wkap.nl>

Electronic Services <http://www.wkap.nl>

Library of Congress Cataloging-in-Publication Data

Injection molding handbook / Dominick V. Rosato, Donald V. Rosato, Marlene G. Rosato. – 3rd ed.
p. cm.
ISBN 0-7923-8619-1
1. Injection molding of plastics–Handbooks, manuals, etc. I. Rosato, Dominick V. II. Rosato, Donald V. III. Rosato, Marlene G.

TP1150.I55 2000
668.4'12—dc21

99-049946

Printed on acid-free paper.

Printed in the United States of America

Path: Home / Plastics & Rubbers/**Manufacture & Processing**/ Injection Molding Handbook (3rd Edition)

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Specialized Injection Molding Processes

Introduction

The versatility of the injection molding process has spawned a whole new generation of machines to fabricate special marketable products. Since 1872 when the first U.S. injection molding machine patent was issued, a variety of specialized machines have been placed in service. They all utilize the basic IMM principle of melting a plastic and forcing the melt into a cavity to produce a molded product. Many specialized IMM are actually well-documented machines and are extensively used for such applications as injection blow molding (1, 3, 4, 13, 14, 18, 54, 318).

In this chapter a few specialized machines will be reviewed. Some of these are themselves a major type of machine and industry on their own (e.g., injection blow molding). Obviously, what gets developed as a specialized machine is based on market requirements. In the extremely competitive lid-and-container field, for example, specialized thin-wall presses reduce cycle times by just seconds—which, in turn, result in a large cost savings. These machines incorporate very advanced techniques to increase the speed of injection into the cavity, temperature and pressure sensors placed directly on the cavity wall, and microprocessors to operate functions of the machine more accurately.

These special machines permit us to save money, produce quality parts with zero defects, meet very tight tolerances and reduce plastic use, reduce energy consumption required for their operation, etc. Examples of some special machines are reviewed in Table (15-1).

For many types of molding, the automation of production using standard machines is not generally possible, or is possible only to a limited extent. In such cases, the optimum solution is to use application-oriented injection molding machines. By appropriate configuration and geometric design of the clamp(s) and injection unit(s), application-oriented injection molding machines can be tailored exactly to a specific application. A very common approach is to take the clamp(s) and injection unit(s) and put them in different positions. Examples include vertical clamp(s) with horizontal injection unit(s) and vertical-injection unit(s) with horizontal in-line clamp(s).

Blow Moldings

Blow Moldings or blow molding machines (BMMs) are divided into three major processing categories: (1) extruded blow molding (EBM) with continuous or intermittent melt (called a parison) from an extruder and

Table 15-1 Examples of specialized injection molding machines

Supplier and Machine Size	How Modified	Productivity Gain	Materials	Applications and Markets
Battenfeld 22-ton through 170-ton	1.2:1 low-compression screw; 30,000-psi high-pressure injection cylinder; accumulator.	Thinner wall sections and more complex parts possible.	Polyamide-imide	Electrical connectors
750-ton	Two parallel injection units; 180-deg rotary table on movable platen.	Eliminates secondary operations.	Two materials, for example, engineering/commodity resins.	Medical parts
50-ton through 170-ton	Two 1-oz, 45-deg injection units; special mold has hydraulically actuated stays to admit sequential shots from each cylinder while clamp is shut.	Eliminates secondary operations; faster clamp cycle than rotary table.	Two materials, for example, rigid/flexible PVC	Pipe fittings, rain gutters
1,300-ton (2 × 650)	Rectangular platen; accumulator; two 650-ton clamp units per machine.	Fewer rejects resulting from platen deflection; fast fill and higher part yield.	Rubber-modified PP	Automotive bumpers dash strips, trim, rocker panels
Epco				
275-ton	Supplied with three interchangeable injection units (5, 14, 28 oz); electroless nickelplated screw.	Eliminates materials' degradation with small molds and permits rapid cycling of larger molds.	Teflon TFE	Chemical process pipe fittings
HPM				
700-ton	Higher watt-density (1000°F heater bands; 150 cu in./s injection accumulator; 75 oz, 26,000 psi) injection units.	Longer heater service life; fewer complex part rejects; increased thin-walling ability.	Ultem polyetherimide	R & D foamed thin-wall parts, thin-wall TV cabinets
1,000-ton	Blower-cooled injection cylinder; auger starve-feeder; double wave screw.	Lower material costs vs. pellet.	PVC dry-blend	Pipe fittings
1,500-ton	Stacked 28-oz injection units; rotary mold indexing table.	Eliminates secondary operations.	Acrylic, PC	Two-material/color automotive tail lights

Husky				
225-ton	Robotized "cooling conveyor" receives hot preforms without deformation.	Reduces cycle times to 20 from 30 s.	PET	Bottle preforms
225- through 600-ton	More plasticating capacity via 25D extrusion screw and higher-wattage heater bands; can be equipped with extra accumulator for rapid fill of 5-gal pails and other large containers.	Allows higher mold cavitation to increase part yield per shot; permits thin-walling large container size.	High-flow PE and PP	Containers
200-ton	Overhead label conveyor and photoelectric sensors on mold face.	Eliminates secondary labeling.	PE, PP, PS	Inmold labeled containers
Klockner Windsor 440-ton	Parting-line injection; vertical clamp; two-station shuttle.	Eliminates secondary operations.	Flexible PVC	Automotive window frame bezels
375-ton	Vertical tie-bar spacing extended to accommodate 16-cavity stack mold with a shuttle plate between each pair of parting lines.	Eliminates secondary operations.	HDPE	Paperboard, plastic 1-qt oil cans
Ludwig-Engel 275-ton 385-ton	Reinforced platens; "coining" clamp; high-speed, high-pressure injection control closed-loop CC80 process control.	Reduces part stress, warpage, and rejects.	Acrylic	Home entertainment and computer video disks
70-ton through 165-ton	"Coining" clamp, accumulator.	Remelt gate area, eliminates turbulence lines and improves yield.	Acrylic, SAN, engineering thermoplastics	Optical lens precision parts
Newbury				
Newbury 30-ton	1,000°F cartridge heaters; thicker injection cylinder walls; injection pressure increased to 40,000 psi, accumulator injection.	Longer machine and heater service life; ability to thin-wall part sections to 60 mils.	Polyarl sulfone	Aerospace electronics
Van Dorn				
300-through 1,000-ton	Press-integrated quick mold changer.	Cuts setup time.	NA	Short- and medium-volume production runs
75- through 1,000-ton	Sealed hydraulics; nylon tie-rod bushings and platen support shoe faces.	Prevents rejects from part contamination.	NA	"Clean room" medical, electronic, and aerospace components

which principally uses an unsupported parison (Fig. 15-1); (2) injection blow molding (IBM) (Fig. 15-2); and (3) stretched or oriented EBM (SEBM) and IBM (SIBM) (Fig. 15-3). These processes usually offer different advantages in producing different types of products based on the plastics to be used, performance requirements, production quantity, and costs (22). Approximately 10 wt% of all plastics consumed worldwide are blow molded. About 75 wt% of all blow molding is by extrusion and 25 wt% by injection. Modified processes such as IBM with rotation and dip IBM also produce a small amount of plastics. (For information on the history of blow molding see Chap. 17, History, Blow Molding.)

Blowing molding lines use an extruder to produce a parison(s) for EBM and an injection mold machine to form a preform for IBM. In turn the hot parison or preform is located in a mold. Air pressure through a pin-type device will expand the parison or preform to fit snugly inside its respective mold cavity. Blow molded products are cooled via the water cooling systems within mold chests that can include channels (Figs. 15-4 and 4-116). After cooling, the parts are removed from their respective molds.

The nature of these processes requires the supply of clean compressed (usually) air to "blow" the hot melt located within the blow mold. Pressures of at least 30 to 90 psi (0.21 to 0.62 MPa) for EBM and 80 to 145 psi (0.55 to 1 MPa) for IBM are usually required. Some of the melts may require pressures as high as 300 psi (2.1 MPa). Stretch EBM or IBM often requires a pressure up to 580 psi (4 MPa). The lower pressures generally create lower internal stresses in the solidified plastics and a more proportional stress distribution; the higher pressures provide faster molding cycles and ensure conformance to complex shapes. The lower melt stresses resulting from lower pressures provide improved resistance to all types of strain (tensile, impact, bending, environment, etc.). Different techniques can increase production by 20 to 40%. For instance, one can use carbon dioxide or aggressive, turbulent chilled air at about −35°C (−30°F) and allow it to

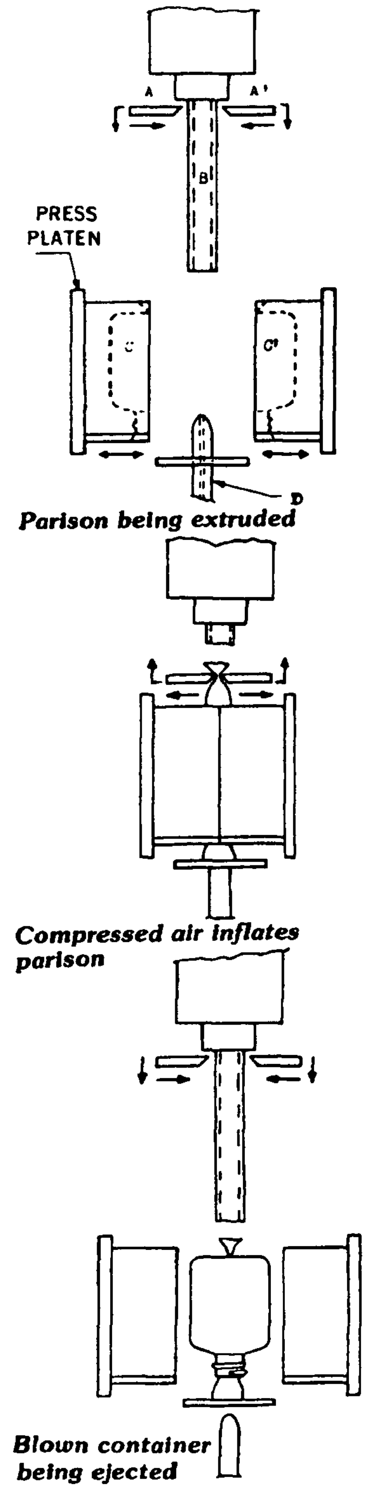


Fig. 15-1 Extrusion blow molding stepwise schematic.

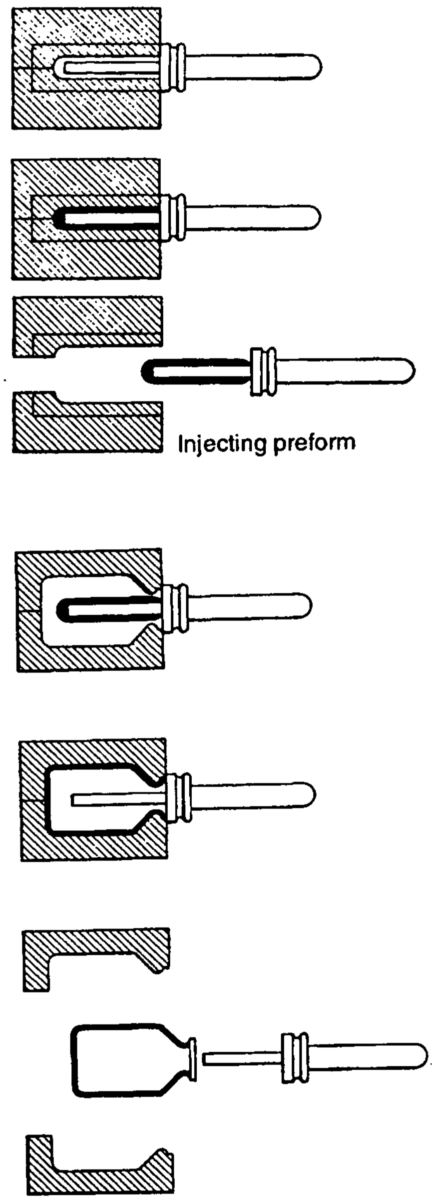


Fig. 15-2 Injection blow molding stepwise schematic.

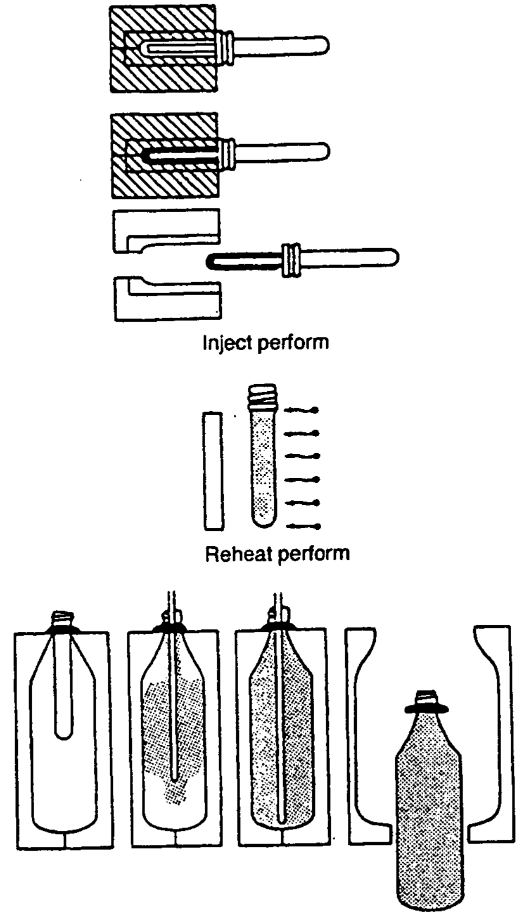


Fig. 15-3 Stretched IBM stepwise schematic.

escape via several channels through the blow pin during a single blowing cycle.

Injection Blow Moldings

Injection blow molding with its noncontinuous melt (preform) from an IMM principally uses a preform supported by a metal core pin (Figs. 15-5 and 15-6). There are three stations or stages in the process.

The first stage injects hot melt through the nozzle of an injection molding machine into a mold with one or more cavities and core pins to produce the preform. The plastic is plasticized by the conventional injection molding procedures described in this book. There is usually more than one cavity. An exact amount of plastic enters each cavity. These molds are designed as in regular IMM molds to meet the required blow molding melt temperatures and pressures. After injection of the melt into the mold cavity(s), the two-part mold opens with melt remaining in a hot stage sufficient not to sag but capable of being blown into the second station.

The core pin(s) carry the hot plastic preform to the second stage of the operation

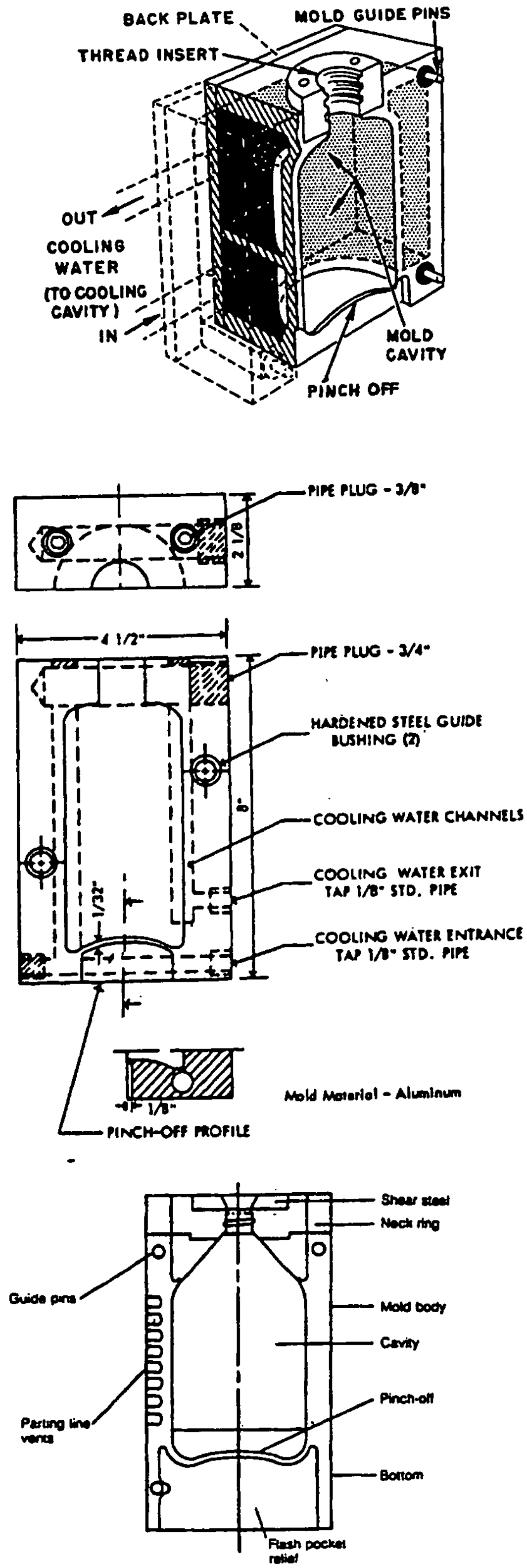


Fig. 15-4 Blow mold flood cooling.

where a two-part mold has the desired mold cavity(s) for blow molding. Upon the mold closing in this second stage, a gas, usually air is introduced via the core pin(s), producing the desired blown product(s). Compared to EBM the preform cavity is designed so that upon stretching, the plastic assumes a rather precise thickness, thereby eliminating wastage. Figure 15-7 provides the complete cycle for IBM.

Controlled chill water usually at temperatures from 40° to 50°F (4° to 10°C) circulates through predesigned mold channels around the mold cavities and solidifies the blown parts. This two-part mold that did the blowing opens when the part(s) solidify. In turn the core pins carry the blown parts to the third stage. In that stage the parts are ejected. Ejection can be done by using stripper plates, air blowing, combination of stripper plate and air, robots, etc.

The IBM procedure allows one to use plastics that are unsuitable for EBM (unless certain types are modified). Specifically, it can handle those plastics with no controllable melt strength, such as the conventional polyethylene terephthalate (PET), which is predominantly used in large quantities with the stretch IBM method for carbonated beverage bottles (liter and other sizes). Another major advantage of IBM over EBM is that the initial preforming cavities are designed to have the exact dimensions required after blowing the plastic melt as well as accounting for any shrinkage, etc. that may occur. Furthermore, no flash or scrap is produced. Neck finishes, internally and externally, can be molded with an accuracy of at least ±4 mil (0.10 mm). IBM also offers precise weight control in the finished product, accurate to at least ±0.1 g.

The IBM preform is a tube, somewhat similar to a laboratory test tube. The tube is hollow and matches the shape of the rod. The preform is used to fabricate the injection blow molded product either in a one-step or two-step operation. The one-step operation goes from the injection molding to the finished blown product, whereas in the two-step operation the preform is first produced in a conventional IMM and this cooled preform

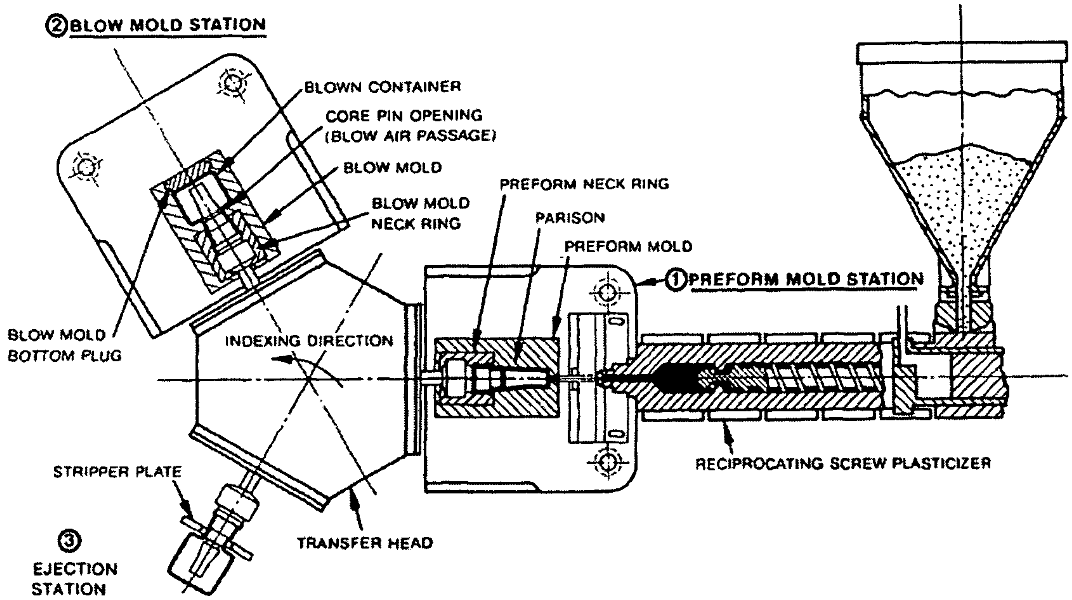


Fig. 15-5 Example of three-station IBM schematic that includes the IMM.

is later put into another machine where it is reheated and blown to produce the product. The two-step operation permits preforms to be stored for further processing in the second step only as the finished product is required.

The mold to form hollow parts is generally made from aluminum (Al). It can have water jackets, flood cooling, cast-in tubing, and/or drilled cooling lines (Chap. 4). Aluminum provides faster heat transfer than steel. However, steel is also used to provide improved wear resistance, handling, and longer life cycles for certain type products and operations. An isolated area of an Al mold such as a thread or a pinch-off, can be inserted with steel to extend the Al longevity. All molds

Fig. 15-6 View of three-station IBMM; in rear right are injection preform molds, in rear left are blow molds, and in front is the stripper plate for removing containers.

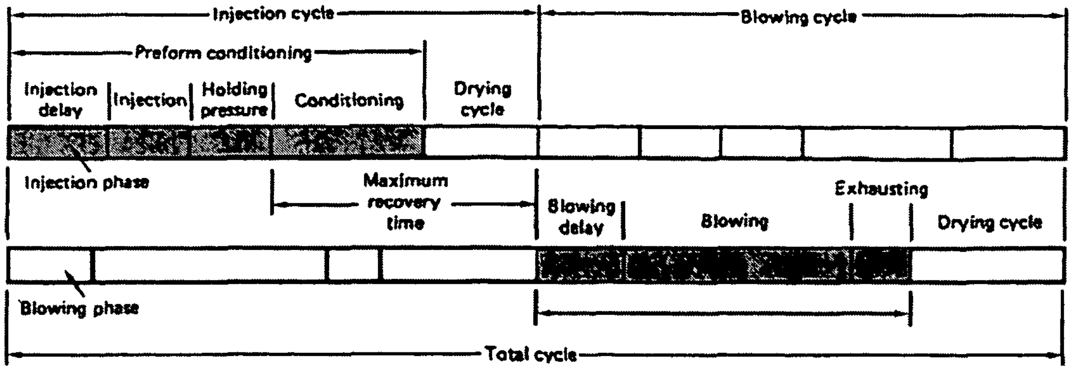


Fig. 15-7 IBM complete cycle.

can include air ejection systems to remove parts.

Stretched Blow Moldings

Using stretched or oriented EBM and IBM one can obtain bioriented products, which provide significantly improved performance-to-cost advantages (Figs. 15-8 and 15-9). Initially most of the product developments were confined to SEBM for carbonated beverages, but later these containers were used with other liquids, foods, cosmetics, paints, detergents, etc.

High speed IBM and EBM take the extra step in stretching or orienting. For example, orientation in an IBM bottle can be made simultaneously in both the longitudinal and hoop directions. With EBM the parison can be mechanically gripped at both ends of the hot tube in the mold, stretching it longitudinally, and blown to provide the circumferential stretching. Injection blow moldings can be stretched in a similar manner or a rod can be placed within the blown part to apply the longitudinal stretch. These processing techniques brought IBM and EBM into the forefront of plastics manufacturing. Almost immediately after being commercially

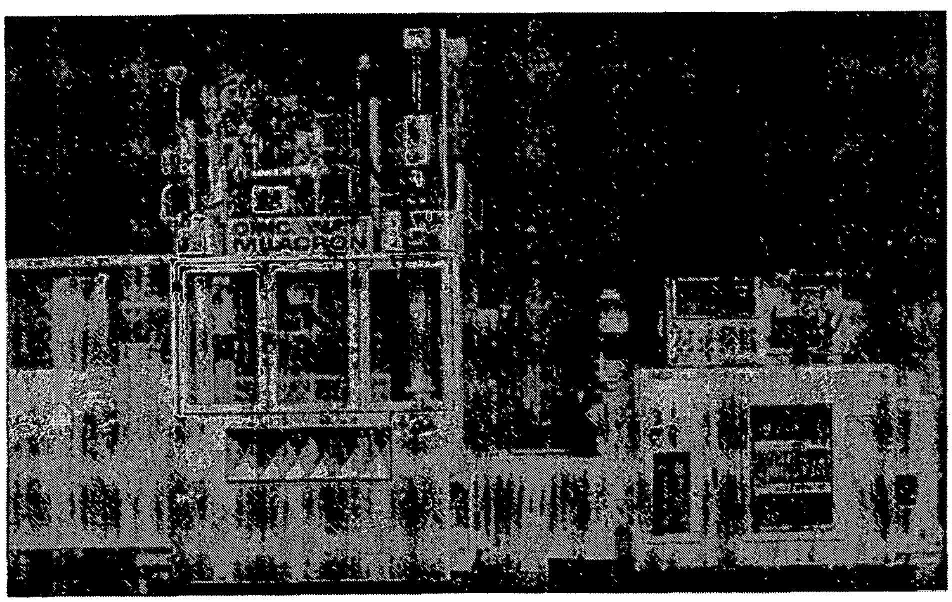


Fig. 15-8 Milacron's integrated one-step stretched IBM producing biaxially stretched oriented containers.

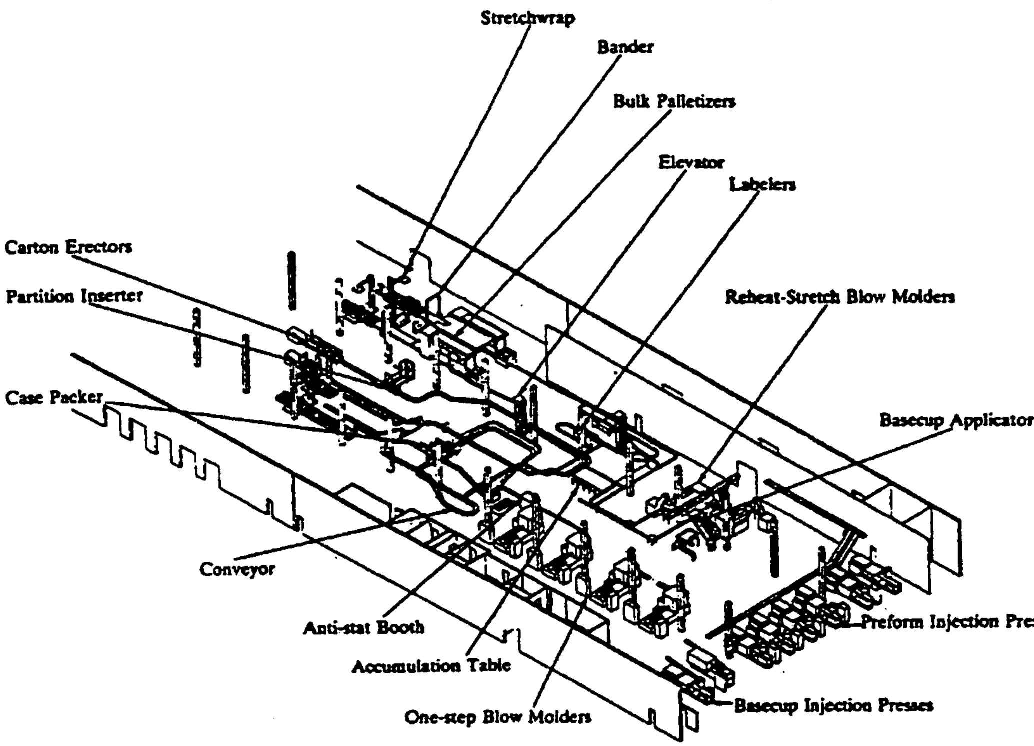


Fig. 15-9 Example of a two-step injection stretch blow molding production line producing PET carbonated beverage bottles.

developed and accepted by the market just a few decades ago, stretched blow molding became the most common IBM process. Prior to that time the stretched IBM process was poised for takeoff but the banning of acrylonitrile plastic (AN) by the government (because of concerns about contamination, which were later shown to be unwarranted) stalled further development of stretched IBM until PET plastics became available (Chap. 17, History).

Biaxially stretching the melt before it is chilled produces significant mechanical improvements with savings in heating energy and material consumption (Chap. 5, Orientations). This technique allows one to use lower grade plastics and thinner walls with no decrease in strength; both approaches reduce plastic material costs. Many plastics have improved physical and improved barrier properties. The process also allows wall thickness to be more accurately controlled. Draw ratios used to achieve the best properties in PET bottles (typical 1- to 3-liter carbonated beverage bottles) are about 3:8 in the hoop direction and 2:8 in the axial (longitudinal) direction. These ratios will yield a bottle with a hoop tensile strength of about 29,000 psi (200 MPa) and an axial tensile strength of 15,000 psi (104 MPa). Examples of what occurs when stretching or orienting plastic materials are shown in Table 15-2.

As in nonstretched blow molding, there are inline and two-stage processes. With inline processing, the complete process takes place on a single machine. The two-stage process requires two machines, one for molding the preform(s) or extruding the tube or parison and a second machine to take the preforms or tubes, reheat them, and blow them. Originally the two-stage systems had higher output rates because they did not require the critical temperature control of the crystalline PET plastics needed in the inline system. However, with modifications in the PET plastic materials, inline systems now provide higher output rates.

Table 15-2 Example of increasing tensile strength and modulus for polypropylene thin constructions

	Stretch (%)				
Properties	None	200	400	600	900
Tensile strength (psi)	5,600	8,400	14,000	22,000	23,000
Elongation, at break (%)	500	250	115	40	40

Directional orientation versus balanced orientation of polypropylene films

Properties	As Cast	Uniaxial Orientation	Balanced Orientation
Tensile strength (psi)			
MD[a]	5,700	8,000	26,000
TD[b]	3,200	40,000	22,000
Modulus of elasticity (psi)			
MD	96,000	150,000	340,000
TD	98,000	400,000	330,000
Elongation at break (%)			
MD	425	300	80
TD	300	40	65

[a] MD = machine direction.
[b] TD = transverse direction and direction of uniaxial orientation.

Originally stretched blow molding was done predominantly with PET (after initial production runs with AN). Later different plastics were used in addition to PET. They included PVC, ABS, PS, AN, PP, and acetal (although most TPs can be used) (Table 15-3). The amorphous types, with their wide range of thermoplasticity, are easier to process than the crystalline types such as PP. If PP crystallizes too rapidly, the product is virtually destroyed during the stretching. Clarified grades of PP have virtually zero crystallinity and overcome this problem. The stretching process takes advantage of the crystallization behavior of the plastics and requires the preform or parison to be temperature-conditioned before being rapidly stretched and cooled into the product shape.

Table 15-3 Examples of stretch blow molding processing conditions

	PVC	PET	AN
Melting (°F)	400–500	475–510	475–525
Glass-transition (°F)	170–180	150–180	220–230
Orientation (°F)	175–225	180–210	260–290
Specific gravity	1.4	1.4	1.1

Stretched Blow Moldings with Handle

Most people are familiar with and recognize that the EBM process can include a "blown" handle, like the very popular blow molded milk HDPE containers. What many do not recognize is that the SIBM process produces a handle that is solid, not blown (although probably someone has produced a blown handle design). Figure 15-10 shows an integral handle design that was issued in the past by a French patent (number 1,192,475) to the Italian company Manifattura Ceramica Pozzi SpA. This schematic shows (1) a precision molded neck that includes the plastic solid handle, (2) a preform core and blow pin, (3) a basic water-cooled bottle female mold, and (4) the injection nozzle of the injection molding machine.

Figure 15-10 shows a traditional jug handle above the blown portion of the container. The handle is molded as part of the preform and is not disturbed when the container is blown.

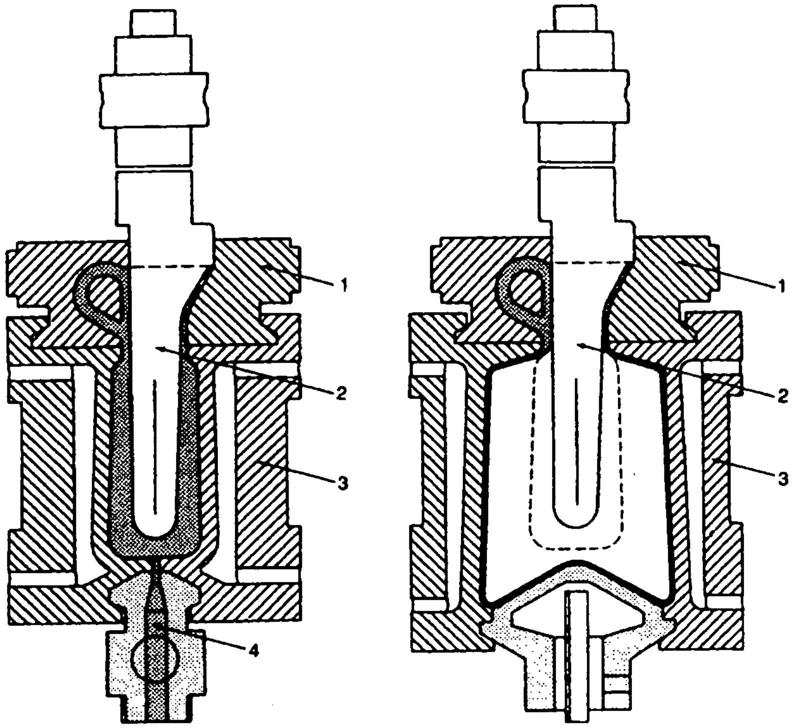


Fig. 15-10 Schematic of stretched injection blow molding with a solid handle.

A direct extrapolation to stretch blow molding technology would incorporate the jug handle preform from the neck to the blown section or below the neck.

Stretched Blow Molding Operation Specialties

Other techniques have been developed to produce stretched bottles and containers offering advantages such as processing at lower temperatures, pressure, etc. these will be described next.

Injection moldings with rotation Molding with rotation (MWR), also called injection spin molding or injection stretched molding, combines injection molding and injection blow molding with melt orientation (Dow Chemical patent). It uses the same the equipment as that used commercially for injection molding except that the mold is modified.

This technology is most effective when employed with articles (1) having a polar axis of symmetry; (2) having reasonably uniform wall thickness; and (3) whose dimensional specifications and part-to-part trueness are important to market acceptance. Note: Within these requirements are many parts having variable surface and wall geometries.

Initial "target" applications have been in the bottle and jar market areas. However, the use of this technology is not restricted to those particular shapes or markets. Practically any article, container, or blown or injection-molded part having one surface reasonably rotationally symmetrical can be fabricated by MWR.

The MWR process asks no sacrifice of either cycle time or surface finish. Both laboratory and early commercial runs identify good potentials for reducing cycle time; for either reducing the amount of resin required or improving properties with the same amount of resin, or both; and for substituting less expensive resin while achieving adequate properties in the fabricated part.

The MWR process is a fabrication method using a rotating mold element in the injection

molding machine. The end-product can come directly from the injection molding machine mold or be a result of two-stage fabrication: making a parison and then blow molding the parison. The two-step process can be "integrated": inline injection blow or separate operations for the injecting molding of parisons with reheating and blowing at separate stations.

Orientation of the molecules within a thermoplastic mass has a direct effect on molded end properties and is the subject of many articles and reports. Injection molders commonly try to minimize the unidirectional orientation resulting from essentially linear mold fill. Shear producers may induce lateral orientation by different stretching (tentering) techniques. Blow molders anticipate and plan for certain structural improvements that result from biaxial orientation occurring during the blowing process.

Plastic fabricators know that minimizing unidirectional flow orientation usually results in better performing end-products. The know-how of polymer rheology and processing temperature, implemented with varying mold fill techniques and end-product design geometries, all are used to minimize problems associated with uniaxial orientation.

The MWR process developed by Dow took a radically different approach. Instead of seeking to minimize uniaxial orientation or its adverse affects, Dow research sought a practical technique by which controlled multiaxial orientation could assure optimum properties (for the resin used) in the fabricated end-product.

The MWR process permits fabricators to control molecular orientation and thus produce top-performance end-products. It permits a balancing of resin temperature, resin rheology, pressures, time, and either mold core or mold surface rotation to achieve a carefully controlled degree of multiaxial orientation within the thermoplastic resin mass.

During fabrication using the MWR process, two forces act on the polymer: injection (longitudinal) and rotation (hoop). The targeted "balanced orientation" is a result of those forces. As the part wall cools, additional high-magnitude, "cross-laminated" orientation is developed (frozen-in) throughout the wall thickness. Note: that orientation on molecular planes occurs as each "layer" cools after injection.

This orientation can change direction and magnitude as a function of wall thickness. The result is analogous to plywood—and the strength improvements are as dramatic. In the MWR process, there are an *infinite* number of "layers," each of which has its own controlled direction of orientation. By appropriate processing conditions, both the magnitude and direction of the orientation can be varied and controlled throughout the wall thickness.

MWR technology produces parts having greatly increased tensile strength compared to the same parts conventionally molded. Because MWR-type improvements are based on balanced multiaxial orientation, the gain in tensile strength also directly correlates with that in practical toughness.

In the gross sense, stress crack agents cause the failure of molded plastic parts by attacking the chemical bonds of the molecules. Failure normally occurs as a crack perpendicular to the direction of greatest weakness. With MWR technology, the internal structural bonding of the plastic part is greatly improved through the multiaxial "laminar" orientation of the molecules. This often results in a measurable improvement in stress crack resistance of the molded part.

Note: Stress crack behavior is dependent on so many variables—resin used, part thickness, part shape, stress crack agent, environment of use, etc.—that each part must be analyzed carefully in its own right. In any case, the stress crack resistance of a part molded with MWR technology can be improved to a commercially significant degree.

Parts molded of polymers that normally exhibit crazes as a predecessor to catastrophic failure can be improved significantly by fabrication with MWR. For common styrenics, the yield strengths of parts having MWR-balanced orientation are significantly higher than those of conventionally molded parts.

Additionally, the mode of failure may become shear yielding because of the high (balanced) orientation provided by MWR. When this is accomplished, crazes, as a form of failure, will not occur.

The effect of cycle time on injection molding economics is great. With MWR, one potential for reducing cycle time relates to the ability to obtain satisfactory end-product performance with less polymer. This can result in a shorter cycle because less polymer requires less heat, which means a shorter cooling time.

Another potential for reduced cycle time occurs because injection molding with MWR is most effectively done when plastic melt occurs at a much lower temperature [≈100°F (≈38°C); lower for styrenics] than would be used for injection molding without MWR.

Cycle times are dependent not only on plastic shot weight and temperature but also on all the variables in a given plant operation. It is reassuring therefore that a number of laboratory tests on cycle time have shown that the cycle time with MWR is at least equal to that of injection molding without MWR.

Mold design, although somewhat different from current practice, is part of the Dow MWR technology package. It has been readily acquired by several commercial injection mold builders working with Dow and/or licensees.

As is common with conventional injection molding, MWR also results in parts having excellent dimensional properties. In addition, MWR permits parts with high length-to-diameter ratios to be molded without problems of core deflection and consequently thinner–thicker sections in the part wall.

With core rotation during MWR, the pin "self-centers," and part wall uniformity is excellent. The final molded part therefore is uniformly strong about its circumference. This fact has particular value if the molded part is a parison. Parisons fabricated with MWR can be reheated and blown without problems caused by wall eccentricity. In injection molding with MWR, part designers and engineers should keep in mind that significant part wall thickness variation and surface geometry variation are possible, if desired.

A basic profile of injection molding conditions to be used with MWR is given below:

- Any orientable injection-moldable plastic resin
- Temperature at 100°C (212°F) or lower
- High injection pressure
- High hold pressure
- Rotation—before, during, and after mold fill
- Rotation and injection controls

Dip Injection Blow Moldings Since the onset of the first blow molding of hollow articles, the industry has asked for a scrap-free energy-efficient process that allows one to use low-cost tooling combined with short procurement times. Extrusion blow molding became the most common process to blow hollow articles for these reasons. However, the inherent disadvantage in finishing the neck and bottom through mechanical shear action compelled the industry to seek out other methods.

Injection blow molding was developed to overcome this latter drawback and further to improve the tolerances required for safety neck finishes and plug fitments. However, tooling costs were high because technically two molds are necessary to produce the hollow article: a preform mold and a blow mold. Both molds have to be constructed to very close tolerances [±0.005 in. (0.013 cm)]. In addition, energy requirements are substantially higher than for extrusion blow molding because of the need for hot-water units to condition the preform.

When dip blow molding entered the market, the industry quickly realized that this process combined the advantages of extrusion and injection blow molding. It allows one to inject the neck finish precisely as in injection blow molding, but without requiring intricate preform molds that led to the name NECK injection blow molding (Fig. 15-11) by FGH Industries, Inc. The molds are simple and can be built in the same time as extrusion blow molds. This process does not require energy-consuming hot-water units, clamp pressure to the neck finish area only, or a high-pressure injection phase to form the preform.

Blow Molding Shrinkages

The shrinkage behavior of different thermoplastics and geometry must be considered. Without experience, trial and error must determine what shrinkage will occur

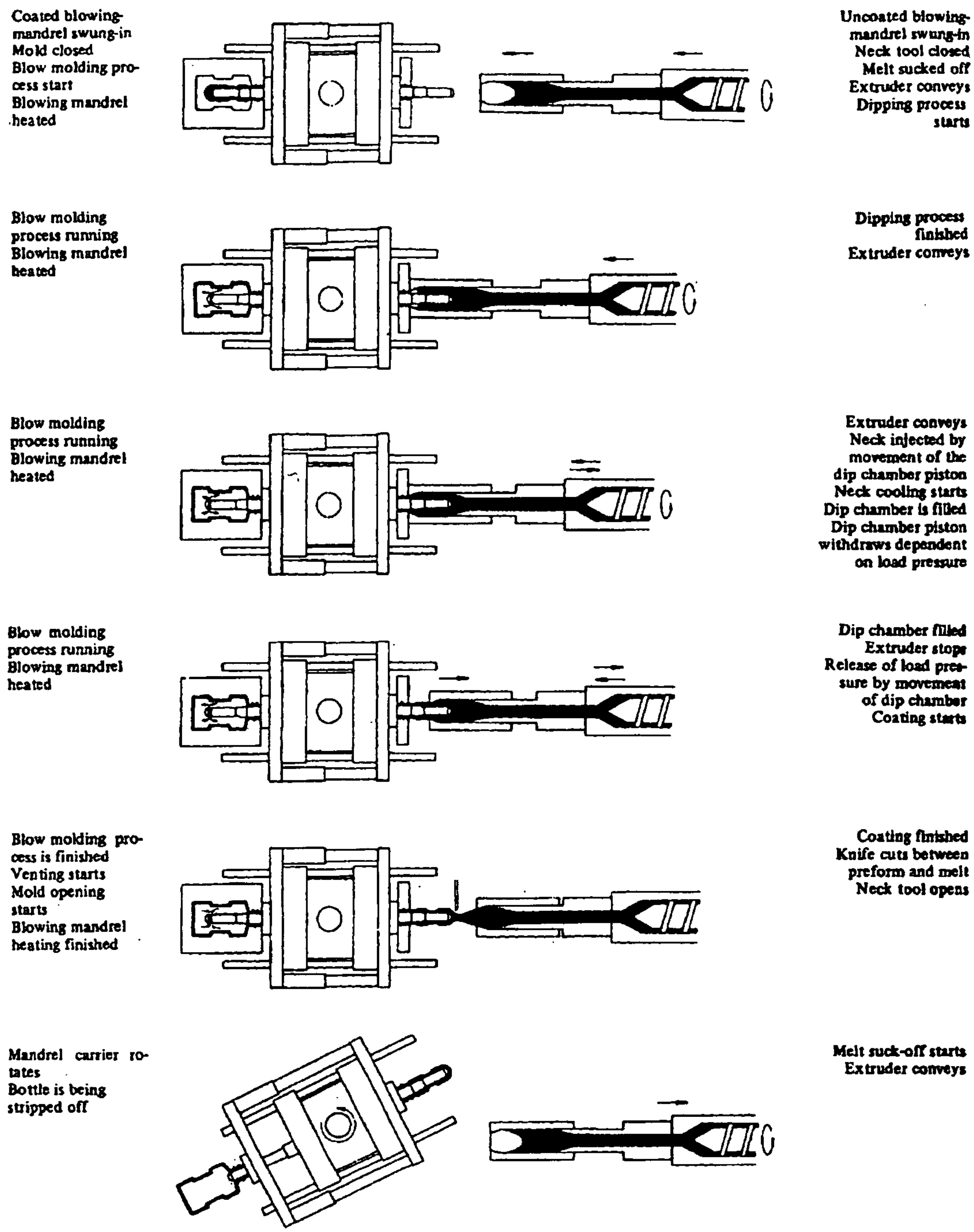


Fig. 15-11 Dip injection blow molding process.

immediately at the time of fabrication and what time period is required after molding (usually up to 24 h) to ensure complete shrinkage. Coefficients of linear expansion and the different shrinkage behaviors depend on whether the thermoplastic material is crystalline or amorphous. Lengthwise shrinkage tends to be slightly greater than transverse shrinkage.

Most of the lengthwise shrinkage occurs in the blow molded wall thickness rather than affecting a body dimension. With polyethylene, for example, higher shrinkage occurs with the higher density plastics and

those with thicker walls. Lengthwise shrinkage is due to a greater crystallinity of the more linear type plastics. Transverse shrinkage is due to slower cooling rates, which results in more orderly crystalline growth. Part shrinkage depends on many factors such as plastic density, melt heat, mold heat, cooling rate and uniformity, part thickness, pressure of blown air, and control or capability of the blow molding production line.

Troubleshooting

In this section, information is divided alphabetically by problem and divided by the injection molded parison or part defects. Causes and solutions are denoted with "C" and "S," respectively. The first set of guidelines is for injection blow molding where solutions ("S") are provided for processing problems. The second set covers stretched injection blow molding wherein causes ("C") and solutions ("S") are defined.

Cocked necks

S: Movable bottom plug is stuck.

- Reset stripper plate.
- Reduce inject portion of cycle.
- Increase blow air time or pressure.

Color streaks: flow lines

S: Raise back pressure.

- Increase injection pressure.
- Increase melt temperature.
- Open nozzle orifice.
- Change color mix.
- Change color batch.
- Add mixing pin to screw. Reduce injection speed.
- Increase parison mold temperature.
- Dry material.

Contamination (oil or grease on part)

S: Wash parison and blow molds with solvent (especially in neck rings).

- Wash core rods.
- Clean air filter.
- Replace O-rings between molds.

Cracked necks

S: Increase melt temperature.

- Increase neck temperature in parison mold.
- Reduce core rod cooling.
- Increase neck temperature in blow mold.
- Reduce retainer grooves in core rods.
- Check if movable bottom plugs are stuck (rigid materials only).
- Increase injection speed.
- Balance nozzles for even fill.
- Check core rod alignment.
- Check operation of mold temperature controller.
- Check stripper location and speed (especially in styrene).
- Open nozzle orifice.
- Replace O-rings in face blocks.

Dimensional problems

***H* dimension = height**

S: Increase by moving parison and/or blow mold out (add shim).

- Reduce by moving parison and/or blow mold in (remove shim).

***S* dimension = neck finish**

S: Increase by moving parison mold out (add shim).

- Reduce by moving parison and/or blow mold in (remove shim).

***T* dimension (to raise *T*) (*T* = average of two dimensions)**

S: Lower parison mold neck temperature.

- Increase injection time.
- Increase stabilization time.
- Lower blow mold neck temperature.
- Increase core rod cooling (internal).

***T* dimension (to lower *T*)**

S: Increase parison mold neck temperature.

- Increase blow mold neck temperature.
- Reduce core rod cooling.

- Hot line blow mold neck. (*Note*: In some cases, the opposite will happen when the above is done when T is being blown out in the blow mold.)

E dimension = across major and minor axes

S: Refer to T dimension.

Distorted shoulder

S: Increase blow air pressure.

- Shorten cycle.
- Wash out vents in blow mold.
- Increase parison mold temperature.
- Clean or replace (plugged) core rods.
- Increase blow air time.
- Reset or replace stripper.

Engraving

S: Raise temperature of body mold temperature controller.

- Increase melt temperature.
- Sandblast molds.
- Adjust engraving depth and width.
- Adjust vents.
- Increase blow air pressure.
- Clean out engraving.
- Increase blow delay.
- Balance nozzles for even fill.
- Clean, check, and set all gaps evenly in core rod valve.
- Check mold temperature-controller operation.
- Increase venting on blow mold.
- Adjust parison mold temperature.
- Adjust blow mold temperature.
- Increase core pin cooling.

Heavy in center

S: Raise temperature of gate mold temperature controller (parison mold).

- Move nozzles in.
- Decrease core rod cooling air.

Hot spots

S: Increase core rod cooling.

- Reduce injection pressure.
- Reduce melt temperature.
- Lower parison mold temperature in affected area.
- Reset stripper for localized external cooling of core rod.
- Check mold temperature-controller operation.

Inconsistent shot size

S: Increase back pressure.

- Check hydraulic injection pressures for variations.
- Increase screw recovery time.
- Balance nozzles.
- Check for loose or bad thermocouples.
- Check for broken element in mixing nozzle.
- Check mold temperature-controller operation.
- Adjust screw rpm.

Nicks

S: Replace damaged blow mold.

- Clean plastic or dirt out of blow mold cavity.
- Repair or replace damaged parison mold.
- Replace or repair damaged core rod.
- Remove strings from nozzles.
- Remove burrs from parison and blow molds.
- Repair or replace damaged parison and blow molds.
- Wash out vents in blow mold.
- Sandblast blow mold.
- Reset mold in die set.

Nozzle freeze-off

S: Remove contaminated material from nozzle.

- Raise temperature of gate mold temperature controller.
- Increase manifold temperature.
- Increase melt temperature.
- Reduce cycle.
- Open nozzle orifice.
- Check manifold heaters, fuses, and wiring.

Ovality of T and E Dimensions

C: Uneven shrinking

S: Increase temperature in shoulder and/or body area parison mold.

- Reduce temperature in neck of parison mold.
- Lower blow mold neck temperature.
- Increase melt temperature.
- Check operation of temperature-control unit.

Push-up depth

S: Increase blow time and/or pressure.

- Adjust mold and/or bottom plug cooling.
- Lower melt temperature.
- Clean and check core rod valve; set all gaps evenly.
- Check movable plug if used.
- Increase core rod cooling.
- Decrease air pressure.
- Adjust nozzle.
- Increase tip cooling.

Saddle finish (usually apparent with oval T and E; try to correct oval T and E)

S: Parison not packed up tight enough; add inject or screw time and/or screw time and/or pressure.

- Increase retainer grooves in core rods.
- Reduce parison mold neck temperature.
- Increase or decrease cushion.
- Increase holding pressure.
- Increase cooling time.

Short shots

S: Clean nozzle.

- Open nozzle orifice.
- Increase high injection pressure.
- Increase packing pressure.
- Increase injection time.
- Increase melt temperature.
- Raise all parison mold temperatures.
- Increase back pressure.
- Increase screw recovery stroke.
- Lengthen cycle time.
- Check and clean nonreturn valve on end of extruder screw.
- Adjust screw rpm.
- Increase screw speed.
- Increase cushion.
- Clean out hopper and throat.

Sticking of parison to core rods (core rod too hot)

S: Decrease cushion.

- Reduce melt temperature.
- Pack parison harder (increase injection pressure and/or time).
- Reduce screw speed.
- Add stearate (release agent).
- Increase back pressure.
- Adjust core rod temperature.
- Check mold temperature-controller operation.
- Check for folds in bottom section.
- Increase internal and external air cooling.

Stripping difficulties

S: Increase stripping pressure.

- Check core pins for burrs.
- Add lubricant to polymer.
- Adjust stripper bar alignment.
- Check V groove depth.

Sunken panels

S: Increase blow time.

- Reduce blow mold temperature.
- Shorten injection/transfer portion of cycle.
- Reduce core rod cooling.
- Add sink correction to blow mold.
- Check mold temperature-controller operation.

Tom parts

S: Lower temperature of gate mold temperature-controller in parison mold.

- Check core rod lock-off in parison mold.
- Check nozzle seats.
- Reset nozzles.
- Check parison mold part line.
- Lower melt temperature.
- Move nozzles out.
- Add injection and/or screw time.
- Replace nozzles.

- Check to see that mold temperature controller is functioning properly.

White or black marks on neck finish caused by gas burning

S: Lower melt temperature.

- Reduce injection speed.
- Lower temperature in neck of parison mold.
- Vent (relief) the neck ring of parison mold.
- Open nozzle orifice.
- Check mold temperature-controller operation.
- Reduce ram speed.

The following guidelines are for stretched injection blow molding

Air bubbles in the preform

C: Air entrapment due to too much decompression in plastifier

S: Check dryer settings.

- Increase back pressure slightly.

Bands of thick and thin sections in part wall

C: Improper settings on heat zones (some zones colder than others)

S: Ensure uniform temperature from capping ring to tip.

C: Not enough time for equilibration of preform before blowing

S: Add equilibration time.

- Change heat zones.

Bands or vertical stripes on the preform

C: Too much heat at specific area on preform

S: Reduce heat.

C: Improper rotation for vertical bands

S: Check rotation speed.

Blemishes on part

C: Dirt in molds

S: Blow molds should be cleaned.

C: Water droplets forming in molds or sweating, causing condensation

S: Increase mold temperature slightly to alleviate condensation.

Cloudiness

C: Melt temperature too low

S: Increase melt temperature slightly.

C: Moisture in injection molds

S: Check for condensation on cores or in cavities.

- Increase water temperature in injection molds.

Drag marks on preform

C: Injection mold damaged or scratched

S: Polish and possibly rechrome cores and cavities

Fish eyes or zippers

C: Scratch marks on preform surface (normally caused by preforms contacting each other after being ejected from injection mold while still hot)

S: Minimize contact of preforms after injection and prior to cooling.

Folds in neck area

C: Center rod stretching preform too early

S: Synchronize center rod stretch with air delay timers to get blow air to enter at correct time.

Heavy material in bottom of part

C: Improper preform design

S: Redesign preform.

C: Improper cooling in molds causing heavy amount of material to shrink back

S: Improve mold cooling.

Knit lines appearing in preform

C: Melt not being injected fast or hot enough

S: Increase temperature.

- Raise injection pressure.

Long gates

C: Valve gates in mold operating improperly

S: Clean mold.

C: Incorrect temperature in hot-runner system

S: Check thermocouples.

Mismatch lines on the preform

C: Mold misalignment

S: Check cores and cavities for alignment.

Off-centered gates

C: Center rods not used

S: Use center rods.

C: Poor concentricity in the preform (preform concentricity should be held to 0.005 in. maximum)

S: Check injection mold for concentricity of core rod and cavity.

- Reduce injection speed and pressure.

Pearlescense (haze in container)

C: Preform stretching too fast for heat in preform

S: Increase heat in area showing pearlescense going back to preform.

Preform drooling

C: Valve gates too warm

S: Decrease temperature to valve gates.

C: Not enough packing pressure or time

S: Increase hold time.

Radial rings on preform

C: Moisture condensation on core rods

S: Increase water temperature in molds.

Scratches on part

C: Possible drag marks on preforms from cavity or core of preform

S: Polish core and cavity of preform mold.

Soft necks or deformed capping rings on finished container

C: Too much heat in top area of preform

S: Reduce heating in affected zone. Heat shield may be added to shield capping rings.

Undersized parts

C: Not enough high-pressure air blow time (container not being blown to side wall and held under high pressure to freeze material and set outline of mold)

S: Check mold cooling.

- Check blow pressures and time.
- Check vents on mold.

Yellowing of preform (indicating oxidization through excessive heating during drying)

C: Check drying temperature and time

S: Adjust drying time as required.

Blow Molding versus Injection Molding

Blow molding usually only requires pressures of 25 to 125 psi (0.17 to 1.03 MPa), with certain plastics or shapes needing up to 200 to 300 psi (1.38 to 2.07 MPa). For injection molding, the pressure is usually 2,000 to 20,000 psi (13.8 to 137.8 MPa) and in some cases up to 30,000 psi (207 MPa). As mentioned earlier, lower pressure generally results in lower internal stresses in the solidified plastics and usually a more proportional stress distribution. The result is improved resistance to all types of stress (tension, impact, bending, environment, etc.). Since only a female cavity mold is required in blow molding, any changes entail only half the amount of work as needed in injection molding. But the tight tolerances achieved with IBM are not possible with EBM.

With EBM, the advantages include lower tooling costs and the capability of incorporating blown handle-ware. Disadvantages include the difficulty of controlling parison swell, scrap production, and limited wall thickness control and plastic distribution control.

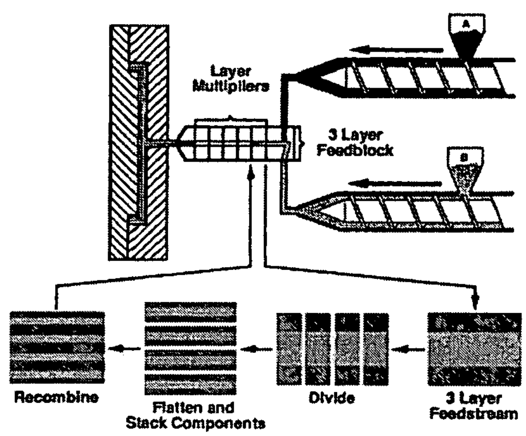
With IBM, the main advantages are that no flash or scrap is produced during processing, it gives the best of all thicknesses and plastic distribution control, critical bottle neck finishes can be easily molded to a high accuracy, and it provides the best surface finish. Disadvantages include its high tooling costs its being limited to incorporating only solid handle-ware. Although in the past IBM was restricted or usually limited to very small products, large and complex shaped parts are now easily fabricated. Similar comparisons exist with biaxial orienting EBM or IBM. With respect to coextrusion, the two preceding methods also have similar advantages and disadvantages, but mainly more advantages for both.

Coinjection Molding

Coinjection molding also goes under the various names of sandwich construction, structural foam construction, double-shot injection, coinjection blow molding (Fig. 15-12a), multiple-shot injection, multiple-layer molding (Fig. 15-12b), in-color molding, in-molding, etc. In this process two or more injection molding barrels are joined together by a common manifold and nozzle through which both melts flow before entering the mold cavity. The plastics can include the same material but with different colors. Some systems use a single plasticator for a single material but produce two shots. The nozzle is usually designed with a shutoff feature that allows only one melt to flow through at any controlled time. Two or more injection units are needed for the two or more different plastics to be coinjected. In addition to the conventional mold used in an IMM, the plastics can be injected in different designed molds such as rotary, shuttle, etc. (Chap. 4) (1, 13, 22, 124, 147, 150, 155, 200, 207, 239, 264, 309, 318, 347, 413, 527, 440, 483, 527, 561).

The usual coinjection laminates the two or more different plastics together. The different materials usually must be compatible enough to provide proper adhesion (Table 15.4). Certain melt processing factors have to be considered to eliminate adhesion compatibility

(a)



(b)

Fig. 15-12 Examples of (a) multilayer coinjection blow molding container and (b) layered coinjection construction.

problems resulting from the unsteady balance of shear forces caused by interfacial instability. Some of these factors can be compensated for by the available plasticator and mold adjustments. Examples of the factors include: (1) different melt temperatures of adjacent layers; (2) plastic viscosity differentials, which should not be greater than 2.4/1; and (3) minimum thickness of a cap (top) layer, which, because it is subjected to a high shear stress, is usually limited to 5–10% of the total thickness. There is a tendency for the less viscous plastic to migrate to the region of high shear stress in the flow channel causing an interface deformation. With a great difference in viscosities existing between adjoining layers, the less viscous material tends to surround or encapsulate the other plastic, resulting in fuzzy interfaces, orange-peel, etc.

If a bond does not exist as required, another plastic is used as an interlayer to provide the adhesion. When bonding layers are desired in these composite structures, a plastic tie-layer is used. Choosing the proper adhesive layer is by no means a simple task since evaluation includes processability, bonding capabilities, and performance in the final coextruded product. There are numerous types offering different capabilities, with EVAL plastics being one of the most important ones. These tie-layers join dissimilar materials in an effort to meld their respective properties. End-products run the gamut from cheese packaging to automotive fuel tanks.

In coinjection molding the first melt shot to enter the cavity provides the skin. The second melt shot provides the core, and if desired the third step would take the melt used in the first shot to apply a skin over the final entrance of the second shot to completely enclose the part with a continuous skin. Coinjection molding provides an excellent way to integrate or entrap recycled contaminated plastic on one or both sides using a barrier virgin plastic—a low cost plastic that provides the bulk flexible or rigid construction. Low density foam core products with thicker walls can be used to provide reduced material costs without sacrificing performance. Properties can also be improved by using a sandwich design.

This form of injection has been in use at least since the 1940s and in the past few decades has become more commercial. It offers many advantages. For example, (1) it combines performance of materials; (2) it permits use of a low-cost plastic such as a regrind; (3) it provides a decorative "thin" surface of an expensive plastic; and (4) it includes reinforcements. Coinjection molding is being redefined today in light of the approaches now available for molding multicomponent parts (automotive taillights, containers, business machine housings, etc.).

Three techniques are offered for multiple-component injection, called the one-, two-, and three-channel techniques. In the one-channel system, the plastic melts for the compact skins and foam core are injected into the mold one after another by shifting a valve (Fig. 15-13). Because of the flow behavior of the plastic melt in the tool and since the first injected plastic for the compact skin cools off under the cooler mold surface, a closed compact skin and core are formed under proper parameter settings. The thickness of the compact skin may be changed by varying the process parameters. This single-channel technique can incorporate either a solid or foamed core. As shown in Fig. 15-13 in the one-channel coinjection system, the sequence of mold filling starts with the skin being injected, then the core, and, in the third stage, the skin polymer is injected again to clear the sprue and seal the skin on the injection side of the part. In this application, a foam core is used. Up to stage 3 all melts have been injected at the conventional high pressure of injection molding. After the skin solidifies, the mold opens to a preset amount and permits the core to foam as shown in stage 4.

The two-channel system (Fig. 15-14) allows the formation of the compact skin and core material simultaneously. With this technique, the thickness of the compact skin in the gate area can be easily controlled (representing a difference from the one-channel system).

The three-channel system (Fig. 15-15) allows simultaneous injection, using a direct sprue gating, of the compact skin and core (foamable or solid). The wall thickness of the

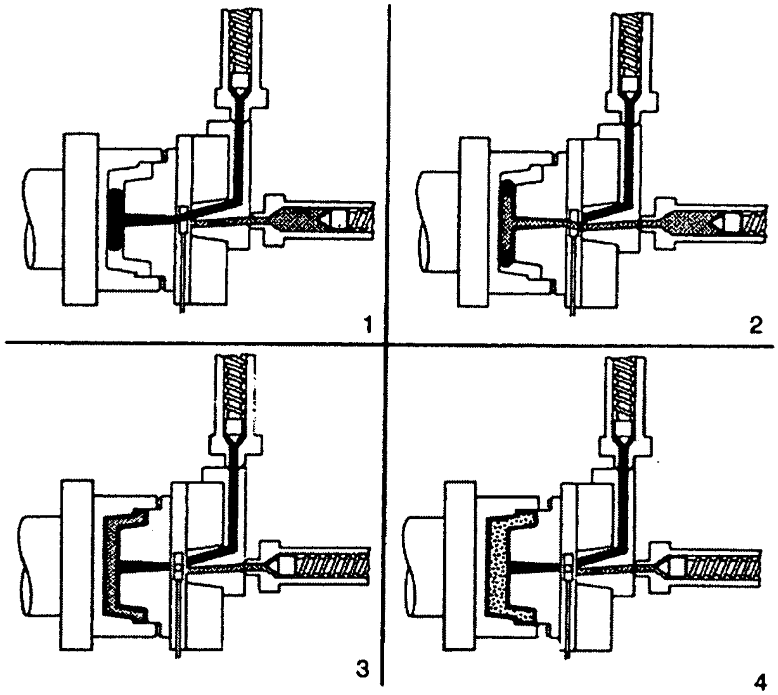


Fig. 15-13 Schematic of one-channel coinjection.

compact skin may be influenced on both sides of the part. With this system, the foamed core progresses farther toward the end of the flow path, compared to the one- or two-channel technique. Also, parts can be designed to be lighter in weight for the structural foam product.

In Fig 15-16, a three-channel system is used to process three different plastics.

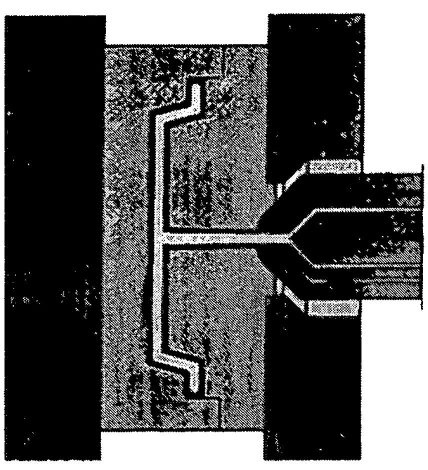


Fig. 15-14 Two-channel coinjection system showing core and outer plastics on both sides of the core.

There are a variety of different coinjection techniques in use. For example, a nonconventional method uses only one single screw barrel. It is called (by Addmix Ltd., London, UK) sequencing screw loading. The system feeds different but compatible plastics volumewise through the IMM's feed throat in a predetermined computer-controlled sequence, which is maintained as the materials travel through the screw. The first plastic entering the cavity forms the aesthetically pleasing skin of the part and the second fills out its core. Any slight degree of mixing of the plastics that might occur is buried in the core.

Injection Molding Sandwich Structures

As just reviewed, skin–core structure is molded using multiple plasticating units that feed their percentage of the total shot to a single injection unit. In turn these layers of plastic melts are injected into the mold. Because of the laminar nature of melt flow, these layers do not mix with each other. Included in the core can be a solid or foam structure as reviewed later in this chapter under

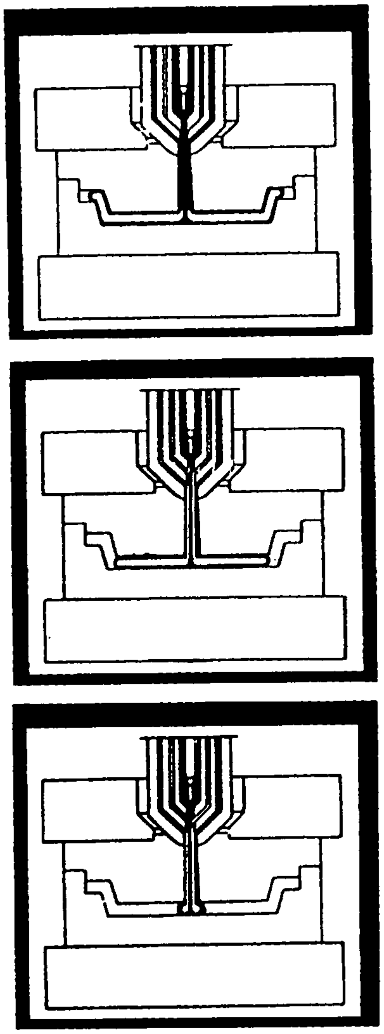


Fig. 15-15 Three-channel coinjection system simultaneously injects two different plastic melts (Courtesy of Battenfeld).

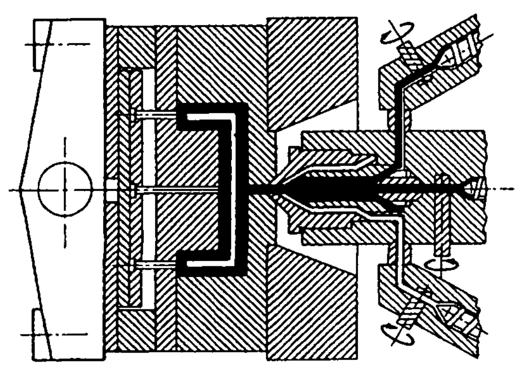


Fig. 15-16 Three-channel coinjection nozzle assembly developed by Billion that is injecting three different plastic melts.

Structural Foam Moldings (see also Chap. 16, Foam Moldings).

Gas-Assist Injection Molding

Gas-assisted injection molding (GAIM), also called injection molding gas-assist (IMGA), gas injection molding (GIM), or injection gas pressure (IGP), uses a gas, usually nitrogen with pressures up to 3,000 psi (21 MPa), with the melt in the mold so that channels are formed within the melt. Different systems are used. The gas can be injected through the center of the IMM nozzle as the melt travels to the cavity or it can be injected separately into the mold cavity. In a properly designed tool run under the proper process conditions, the gas with its much lower viscosity than the melt remains isolated in gas channels of the part without bleeding out into any thin-walled areas in the mold, producing a balloonlike pressure on the melt (1, 13, 150, 155, 264, 309, 347, 447).

This process can be most effective in different size and shape products, especially the larger molded products. It offers a way to mold parts with only 10 to 15% of the clamp tonnage that would be necessary in conventional injection molding.

The technique is practiced in several variations, such as in the usual internal system but also as an external system (where gas is injected between the filled cavity melt and cavity wall just prior to melt solidifying). The process involves the injection of an inert gas, usually nitrogen, into the melt as it enters the mold. This is not structural foam, as no foam core is produced; instead, the gas forms a series of interconnecting hollow channels in the thicker sections of the part. The gas pressure is maintained throughout the cooling cycle. In effect, the gas packs the plastic into the mold without a second-stage high-pressure packing in the cycle as used in injection molding, which requires high tonnage to mold large parts.

Molded-in stresses are minimal. The thick but hollow sections provide rigidity and do not create sink or warpage problems. The cycle time is reduced because the thick sections are hollow. As the gas is not mixed with the

melt, there is no surface splay, which is typical of low-pressure structural foam molding. The finished part exhibits an excellent surface finish with minimum distortion. The nitrogen tank gas pressure is usually about 4,300 psi (30 MPa). Gas injection is being used with commodity and engineering plastics.

Advantages and Disadvantages

GIM is a solution to many problems associated with conventional high-pressure injection molding and structural foam molding. It significantly reduces volume shrinkage, which causes the sink marks in injection molding. Other advantages include:

1. No molded-in stresses (and no sink marks) due to low cavity pressure exerted by gas
2. Lower mold cost because undercuts can be avoided and there are savings on slide actions when required
3. Simplification in certain mold designs
4. Part design flexibility such as mixed thick and thin walls, box sections possible without movable cores, allowing part consolidation and larger complex parts to be molded
5. Lowers clamp force and thus costs for operating injection molding machine (lower energy costs)
6. A shorter cycle time, especially for moldings with large wall-thickness variations
7. Material savings up to 40%, depending on the part configuration
8. Significant reduction of sink marks over ribs and bosses
9. Improved surface finish
10. Part weight reduction, higher strength-to-weight ratio

Parts produced by the GIM method are stiffer in bending and torsion than equivalent conventional injection molding parts of the same weight.

To date, potential limitations exist: Longer production-development lead time is required, it is difficult to control multi-cavity molds (usually greater than four cavities), precision and programmable mold-temperature control is required for consistent wall thickness, and the part has to be designed to place a vent hole on a nonvisible portion.

Basic Processes and Procedures

It is well known that, in the conventional injection molding process, the pressure required to advance the plastic melt increases with the amount of plastic injected (or equivalently, the flow distance). It should be noted that the gapwide average melt viscosity is proportional to the magnitude of the pressure gradient and melt fluidity. Therefore, as the flow length of the melt increases, the inlet pressure has to increase to maintain a certain pressure gradient if the flow is to be kept constant.

With GIM, the pressure requirement is the same as that for the conventional process during the plastic injection stage. Upon the introduction of gas into the cavity, the gas starts to displace the viscous melt, pushing it to fill the extremities of the cavity. Because the gas has essentially very low viscosity, it can effectively transmit the gas pressure without a significant pressure drop to the advancing gas–melt interface. Therefore, as the gas advances toward the melt front, the pressure required to keep the melt ahead of the gas moving at the same velocity decreases, since the effective flow length decreases.

Consequently, the gas pressure required to fill the mold cavity can be lower than the entrance melt pressure needed for the conventional injection molding process. Further, the resulting pressure distribution is more uniform in a gas-injected part. This action induces less residual stresses as the plastic cools down during the postfilling stage. Accordingly, the GIM part can be produced with a lower gas-pressure requirement, which leads to lower clamping tonnage.

Owing to the unique mold design with a built-in gas channel network and dynamic interaction between gas and plastic melt, gas penetration can become very complicated. For example, during the melt injection stage, typically the melt will flow along the gas

channel, which serves as a flow leader and results in the so-called racetrack effect. The significance of the racetrack effect depends on the material properties and processing conditions, as well as cavity geometry. Improper combinations of these parameters will give rise to an air trap and gas permeation into the thin section near the air trap. The gas will take the path along which the plastic melt has the least resistance and largest pressure gradient. Since the pressure drop from the gas tip to the presumably vented melt front is approximately a constant, the flow path that has the least flow length (between the gas tip and melt front) will result in a high-pressure gradient and thus can be permeated by the gas. This is the reason why the gas starts permeating into the thin section moving toward the air trap.

Another common complication associated with uneven gas permeation is the melt-front position immediately before the gas injection. After the gas is introduced into the cavity, typically it starts penetrating the thick-sectioned gas channels. However, once the lower portion of the cavity becomes filled, the pressure over that region starts to build up because the melt can no longer fill in that region, giving its place to the incoming gas. The result is that the gas can hardly penetrate into the lower portion further until the whole cavity gets filled and the plastic starts to shrink. Meanwhile, the gas penetration continues in the upper part of the cavity until it is filled.

In addition to problems such as air trap, gas permeation into the thin section, and uneven gas penetration, other flow-related problems exist, such as gas blow-through. This occurs when an insufficient amount of plastic melt is ahead of the gas front because of the delay of gas injection. This leads to switch-over or hesitation marks along the suddenly decelerated melt front at the switch-over time. It can also cause material degradation associated with the acceleration of the melt driven by the advancement of gas, as well as short shot resulting from low gas pressure or inadequate tool design.

Processes There are basically two types of processes: gas through the nozzle and gas through the runner or cavity (sequential type). In both cases, the mold is partially filled with plastic melt as a short shot. The gas can be introduced simultaneously and/or subsequently with the plastics after some delay time or the plastic flow can be completely stopped by a specially designed shutoff gas nozzle, and a controlled volume of inert gas (usually nitrogen) can then be injected into the center of the melt flow. The combination of high melt surface tension and lower viscosity of the hotter molten plastic in the center of the thicker sections, such as ribs, confines the gas to form hollow areas in the thicker sections of the part. The melt that is displaced by the gas is pushed into the extremities of the tool (mold), packing out the molded part.

The outer surface of thicker sections do not sink because gas has cored them out from the inside and gas pressure holds the plastic against the mold surface during rehardening. The sink in these sections takes place internally rather than on the exterior surfaces of the part, eliminating sink marks. Since the pressure used for final filling of the part is confined to an area defined by the system of gas channels, the resultant force against the sections of the mold is relatively modest so that lower clamping forces on the mold are adequate.

Comparing a gas through nozzle to a gas through cavity process, we see that each has its own pros and cons. Gas through nozzle is good for symmetrical multicavity molds and should not be used with a hot-runner system. Also, the gas cannot be injected simultaneously—plastic flow is stopped; then the gas is injected. Existing molds can usually be employed without much change for this mode, depending on part design.

Gas through a cavity or runner mode offers more flexibility. Hot-runner systems can be easily used. Simultaneous plastic and gas injection is possible. This tends to be a more versatile technique.

In regard to part and tool design guidelines, it is well understood that simultaneous part design, mold design, and process design are important features for the success of any gas-molded part. For GIM as for conventional

injection molding, some guidelines have been established for different plastics, but these may not hold true for all geometries and wall thicknesses. The usual gas channel geometry is either symmetrical or unidirectional relative to the injection gate.

The balance for the plastic and gas flow from the gate is critical. Computer-aided mold fill analysis (short shot) can be a very helpful approach for gate design and location. As a rule of thumb, the width of a rib should be equal to or less than three times the nominal wall thickness and the depth (height) of a rib should be equal to or greater than three times the nominal wall thickness.

A gas flow channel must be continuous and should not loop back upon itself. The plastic melt displaced from the gas flow channel must have some place to go, and the material displaced must be sufficient to pack out the mold. One should provide spillover space in the mold for fine-tuning the flow distance to achieve desired hollow channels.

Procedures There are two different GIM-controlled molding procedures: volume-controlled gas metering and pressure-controlled gas metering. With volume-controlled gas metering, a predetermined quantity of gas is injected, after which the gas pressure decreases slowly (such as in the patented systems from Gain Technologies, Mount Clements, MI, United States and Cinpres, Stafford, England). With pressure-controlled gas metering, the gas pressure is either constant from the beginning or has a defined profile (e.g., low at the start, high during the holding phase) (such as in a patented system from Battenfeld).

Some general comments can be made regarding these processes. The most important precondition from the reproducible operation of the process is homogeneous melt. High gas pressure during the cooling period gives smooth gas channel surfaces, whereas a pressure drop before the melt has fully solidified gives rise to a rough or foamed inner wall structure.

Gas blowing takes the path of least resistance. Thus, parts with wall thickness differences and large areas of uniformly thin walls have to be prefilled with a large proportion of the total quantity of melt. Higher gas pressure leads to lighter molding. Also, the achievable wall thicknesses and surface effects can be more strongly influenced by material modifications than by changes in processing parameters.

The processes can be adopted for use on the usual type of injection molding machines without major expenditures. The gas is introduced through a needle seal nozzle specifically modified for the process. The processes are based on the control of pressure. The pressure and length of the gas injection are regulated during gas introduction. The control of the duration of gas introduction and pressure can be accomplished not only by the signals of the injection molding machine but also by the use of external programmers and signal transmitters.

It appears reasonable to obtain the signal for the injection and then control the time delay and length of the gas introduction through external regulators. With nitrogen a maximum pressure of 300 bar (4,350 psi) can be used. Gas pressure in the usual application is 200 bar (2,900 psi). The pressure can be produced continuously, for example, by compressors. As an alternative, the gas can be injected intermittently using a hydraulically operated piston.

Measurements with transducers placed in the mold as well as theoretical considerations have shown that simultaneous gas injection is not possible. During the injection of the melt, the pressure at the flow front is about 1 bar (14.5 psi). However, the gas pressure remains mostly constant throughout the entire expansion of the cavity. The flow front has to absorb the full difference between the pressure of the gas and that of the atmosphere. The molded part is thus blown out. To prevent the blowout of the part, there must be significant mass accumulation between the gas bubble and flow front. This means that at the boundary a sufficient amount of melt must be supplied during the blowing stage.

However, this is not possible when the gas and melt are injected simultaneously, because in locations where the melt touches the mold, the pressure gradient is the same.

Reinforcement with ribs in the part can be incorporated. Ribs must be designed in such a way that the gas has a free passage in the center from the sprue to the outside. The ribs should not be brought together because this could cause material entrapment.

The gas-filling profile has to be finely tunable with both the simultaneous and sequential methods. Gas introduction is a function of the screw position, with the gas flowing to the internal gas pressure nozzle via a valve. Through the proportional valve, a gas profile can be set on the machine's control system. The screw-position-dependent start of gas injection ensures that, the mold is reproducibly filled.

Molding Aspects

The position of gas bubbles determines the dimensional stability and thus the precision of reproduction of the molded part. Controlling gas bubbles is complicated. Because of the varying amount of trapped gas the weight scatter with GIM when no holding pressure is used is currently ± 0.3 to $\pm 1.0\%$, whereas with conventional injection molding, it is $\pm 0.1\%$. This large weight variation has no negative implications for part quality. In contrast to the example with conventional injection molding, even light parts are properly filled and heavy ones not overfilled.

The repeatability of geometry in the hollow space is essentially dependent on the material and geometry of the mold cavity. Process parameters and process stability have only a small effect. However, surface quality does depend very largely on them.

In general, GIM parts require molds designed specially for the specific process. Faults are more difficult to correct than with conventional injection molding. Also, the optimization phase on commissioning a new mold usually takes longer with GIM molding. The surface quality of thick-wall GIM parts depends above all on the injection technique, and jetting should be avoided during filling.

Marking, even when switching to gas metering, can result if cross sections are too small. With reinforced plastics, the external surfaces are rougher than with conventional injection molding, because the gas holding pressure is lower.

From an environmental viewpoint, no special difficulty arises with GIM. Actually, the level of residual monomers in the nitrogen is extremely negligible. Gas-recovery systems are available and, in terms of the environment and nitrogen consumption, ought to be used.

The holding pressure drops as is usual in the conventional injection molding process. It is replaced by the internal pressure of the gas. The gas presses the solidified melt against the wall of the mold. In conventional injection molding, the holding pressure acts only up to the point of sealing the sprue. Beyond that action, it is no longer effective. This is especially critical for parts with thick walls that have only relatively small gates. During the GIM process, however, the sprue remains open due to gas channel (or with the gas into the runner or cavity); this means that the pressure can be considered constant within the entire cavity. Thus, the space far from the sprue has the same internal pressure as that which is close to the sprue, thereby eliminating shrink spots even in these areas.

Generally, the usual parameters for the material, molds, and machine can be adjusted. Several processing parameters affect gas expansion. For example, an increase in temperature of the plastic material can have the following effects: The wall thickness of the molded part diminishes, reproducibility becomes a problem, and increased risk of blowout occurs. A higher mold temperature results in the reduced occurrence of sink marks, reduced amount of shrinkage, and improved efficiency of gas injection.

A reduction of the injection rate causes the increased risk of blowout and a reduced material cushion in front of the gas bubble. The extension of the metering passage can result in an increased plastic cushion in front of the gas bubble, reduced gas volume, and diminished risk of blowout.

The choice of gas pressure must be suited to the particular molded part. The minimum and maximum pressures can be determined

by measuring pressures in a screw tab using a solid part. The minimum pressure should be chosen so that the gas pressure is higher than the melt pressure during two-thirds of the total gas injection period. The maximum pressure has to be adjusted in such a way that there is no gas disturbance in the melt. As a reference point, Lavall pressure can be used, which states that when the ratio of the melt pressure to the gas pressure is less than 0.5, undesirable turbulence can be expected.

Shrinkage

Compared to conventional injection molding, plastic shrinkage with GIM depends greatly on viscosity. This is because the high mold wall or melt temperature results in minimal wall thickness and thus the inside of the wall has only a slightly higher temperature during demolding than the mold surface. The shrinkage that then takes place is proportional to the difference between the mold and ambient temperature. If one compares a conventional injection molding part of amorphous plastic (Chap. 6) with one produced by the GIM process, the shrinkage of the GIM part is reduced by one-third.

With crystalline plastics, the pressure during the cooling phase has a strong effect on the spherulite formation and thus shrinkage. Investigation has shown a gas-pressure-dependent shrinkage increase at low gas pressure, compared to conventional injection molding. Thin walls result from the formation of hollow space. They possess amorphous outer layers on the mold side, which are missing from the hollow side. The spherulite structure therefore transfers straight into the hollow space without any visible amorphous outer layer.

Summary

In principle, all injection-moldable plastics are suitable for the GIM process, whether they are transparent, colored, filled, or reinforced. Their freeze characteristics are decisive for hollow space creation. Difficulties can arise with quickly solidifying plastics and large, thick-walled cavities. In these examples, good, crease-free surfaces can only be achieved with difficulty. Gas and plastic melt intermix in the border area and are due to gas pressure. These gas–melt mixes are the result of turbulences occurring when a certain gas pressure is exceeded. As a guideline for the maximum value that the gas pressure may serve, the melt pressure should be at least twice as high.

With a reduced gas pressure period, the whole of the hollow space is filled with foam. As previously reviewed, this foaming occurs because the only incomplete cooled melt (mixed with gas) expands along the wall of the hollow space at the start of gas feedback. This effect occurs with polyolefins in particular. To prevent this foaming effect, a low gas pressure should be applied during the gas-filling phase. A stepwise increase of the gas pressure should be programmed for the gas holding pressure phase.

Each GIM process (gas through nozzle and gas through cavity) has its own benefits and limitations based on the part design, complexity, number of cavities, type of mold, tolerance requirements, cost, equipment life, and necessary modifications needed on the injection molding machine.

The part must be designed for the process, but at this stage, engineering knowhow and experience for part design, tool design, and process optimization are continually being advanced in development and experience. To reduce the cost of the trial-and-error approach, it is strongly recommended that conventional computer-aided plastic flow analysis with available gas flow analysis (Chap. 9) be performed.

For each process, many developments have been made for the improved control of gas pressure, volume, injection speed, and time. The new gas equipment now available is more sturdy, thus minimizing day-to-day production problems and resulting in longer production life. The growth of this GIM technology will depend heavily on the cooperation between equipment suppliers, product and mold designers, and plastic molders. This technology has brought about breakthrough

innovations in injection-molding-related applications.

Gas Counterflow Molding

In gas counterflow molding, also called gas counter pressure molding, a conventional injection molding system is used with a separate entrance to the mold cavity providing gas (usually nitrogen) pressurization prior to injecting the melt shot. This back pressure in the cavity can provide an even distribution of melt packing during its cooling cycle. When producing foamed plastic parts, this gas back pressure prevents the blowing agent from expanding until its part skins can form on the cavity surfaces where the gas is vented. Controlled foam expansion is possible with this technique.

Melt Counterflow Molding

As in the case of conventional injection molding, molded products can have unwanted weld line(s). Counterflow uses two separate injection units (or one unit with a melt-splitting device) so that the melt flow within the cavity arrives from different directions. This results in complete elimination of any weld line (or nearly so). Melt counterflow molding can also be used to handle more difficult melt flow requirements, such as the presence of some type of a blockage or restriction in the cavity. It also provides a means to orient flow stress, such as when using liquid crystal plastics or reinforcing fibers (Chap. 11, Counterflow).

Structural Foam Molding

Overview

Structural foam molding is also called foam molding (FM), integral skin foaming (ISF), foamed gas-counter pressure (FGCP), or reaction injection molding (RIM); however, it is usually called structural foam (SF). Up until the 1980s in the United States, the RIM and SF processes were separate. Combining them in the marketplace was to aid in market penetration. During the 1930s to 1960s, LIM (liquid injection molding) was the popular name for what later became RIM and SF. Fig. 15-17 shows the year 2000 structural foam molding machine from the Wilmington Machine Company, Wilmington, NC.

SF is characterized as plastic structures with nearly uniform-density foam cores and integral near-solid skins. The definition of SF by the SF industry is a plastic product with integral skins, a cellular core, and enough strength-to-weight ratio to be classified as

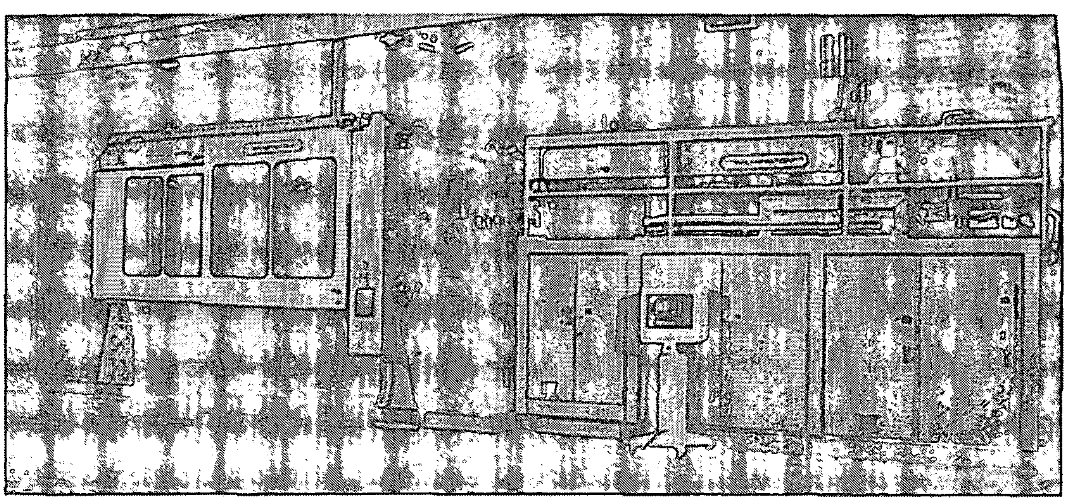


Fig. 15-17 Low pressure 750 T wide platen structural foam IMM from Wilmington Machine.

structural. When these foams are used in load-bearing applications, the foam bulk density is typically 50 to 90% of the plastic's unfoamed density. Most SF products (90%) are made from different thermoplastics, principally PS, PE, PVC, and ABS. Polyurethane is the primary thermoset. Unfilled and unreinforced plastics represent about 70% of products. The principal method of processing (75%) is modified low-pressure injection molding. Extrusion and RIM account for about 10% each.

A great variety of foam products are available from plastic, but these basically fall into two categories: flexible and rigid. The flexible type generally identifies the very large market of principally extruded polyurethane foam for cushioning (for chairs, mattresses, etc.); about 5% of all plastic goes into these flexible foams. Another important flexible type can include the expandable polystyrene (see Chap. 16 on EPS) that is used in special injection molding machines (steam curing). The EPS market represents about another 7% of all plastic used. Within the rigid types are the important structural foam (0.2% of plastic) and reaction injection molding (0.3% of plastic) types, both of which are involved in injection molding.

Performance

The use of SF molding is interesting principally because it provides a three- to fourfold increase in rigidity over a solid plastic part of the same weight. (This three- to fourfold advantage, or even a greater one, can be designed into many applications with solid plastic by using the basic engineering rib design for molds.) SF also permits molding large parts with the same cost advantages that injection molding (solid parts) offers to smaller parts. Thus, large parts with a high degree of rigidity can be molded. The self-expanding nature of SF results in low-stress parts with dimensional stability and less tendency to warp or exhibit sink marks. It also offers thermal and acoustic insulation.

There are other advantages to using structural foam, but there are also disadvantages. Molding cycle time will at least increase by the square of the thickness increase. Moreover, most SF parts are made by a low-pressure technique that causes a surface finish that visually resembles the splay marks found in injection molding. This surface condition, called swirl, is the result of broken bubbles in the surface; techniques such as counter-pressure must be used to significantly remove the swirl finish. Thus, producing conventional low-pressure SF parts can result in higher finishing costs and longer cycle times.

Plastic Materials

Polystyrene, polyurethane, ABS, and polypropylene represent about 90% of the resin used for SF. The remaining engineering resins provide the usual advantages of performance such as increased mechanical creep resistance and heat-resistance properties. Of these engineering resins (polycarbonates, nylon, ABS, PBT, PPO, and acetal), the principal choice has usually been polycarbonate.

Applications for SF are found in computer and business machine housings, appliances, building products, etc.

Characteristics of Foam

A density reduction of up to 40% can be obtained in SF parts. The actual density reduction obtained will depend on part thickness, design, and flow distance. Low-pressure structural foam parts will have the characteristic surface splay patterns; however, the utilization of increased mold temperatures, increased injection rates, or grained mold surfaces will serve to minimize or hide this surface streaking. Finishing systems (e.g., sanding, filling, painting) for structural foam are readily available and have proved to be capable of completely eliminating surface splay. It should be noted, however, that the utilization of techniques to minimize splay can very often result in reduced finishing costs.

High-pressure structural foam parts have generally been found to require little or no postfinishing. Although high-pressure foam parts may exhibit visual splay, surface

smoothness is maintained, and no sanding or filling is required.

Structural foam parts expanded with chemical blowing agents will exhibit increased stiffness because they are normally thicker than solid moldings. Their lower density also provides a higher strength-to-weight ratio when compared to solid moldings. Because of the foamed core within the part as well as its greater thickness, acoustical and insulating properties are enhanced.

Foaming a polymer does not change its chemical structure or its resistance to chemical attack, provided the proper chemical blowing agent and processing conditions are used. Mechanical properties such as tensile and impact strength (Fig. 15-18) and flexural modulus will be lower in foam parts because of their low densities.

The cell structure of structural foams varies quite widely for the various molding processes. In the expansion cast molding process (similar to cold compression molding, not SF molding), the products to be foamed are placed in a cold mold. Then the mold is heated, and expansion takes place relatively slowly, making for slow growth of the cell structure; this results in quite a uniform cell structure. This holds not only for thermoplastic foams produced by roto-molding and the foundry process but also for polyurethanes produced by expansion cast molding.

In injection molding, the cell structure of molded foam varies markedly for various

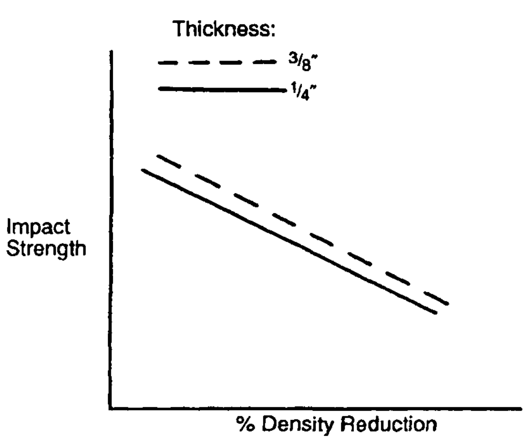


Fig. 15-18 Impact strength of structural foam thickness versus weight.

processes. When the mold is filled with a short shot accompanied by *low* mold pressure, the cell structure shows a wide distribution in cell size across the part cross section. In fact, small random voids may occur in the structure. When the mold is filled under low pressure, the foam density shows a gradient along the flow path, with the highest density at the end of the flow path and the lowest density near the runner. When the mold is filled under *high* injection pressure, no foaming occurs in the mold until a solid skin has been formed. Then the mold pressure is intentionally reduced by either melt egression or mold expansion, permitting the still molten core to foam. These techniques make for uniform cell structure not only across the part thickness but over the entire part.

Design Analysis

For structural foam, mold pressures of approximately 600 psi (4.1 MPa) are required, compared to typical pressures of 5,000 psi (34.5 MPa) and greater in injection molding. As a result, large, complicated parts, 50 lb (22.7 kg), and up can be produced using multinozzle equipment, or up to 35 lb (15.9 kg) with single-nozzle equipment and hot-runner systems. Part size, in fact, is limited only by the size of existing equipment, whereas part complexity is only limited by tool design and material properties. Part cost can be kept in line through such advantages as parts consolidation, function integration, and assembly labor savings.

When an engineering plastic resin is used with the structural foam process, the material produced exhibits predictable behavior over a large range of temperatures. Its stress–strain curve shows a significantly linearly elastic region like other Hookean materials, up to the proportional limit.

However, since thermoplastics are viscoelastic in nature, their properties are dependent on time, temperature, and the strain rate. The ratio of stress and strain is linear at low strain levels of 1 to 2%, and, therefore, standard elastic design principles can be applied up to the elastic transition point.

Large and complicated parts will usually require more critical structural evaluations to allow better predictions of load-bearing capabilities under both static and dynamic conditions. Thus, predictions require a careful analysis of the structural foam cross section.

The composite cross section of a structural foam part contains an ideal distribution of material with a solid-skin outer region and foamed core. The manufacturing process distributes a thick, almost impervious solid skin, which is in the range of 25% of the overall wall thickness at the extreme locations from the neutral axis (Fig. 15-19a). These are the regions where the maximum compressive and tensile stresses occur in bending (18).

The simply supported beam has a load applied centrally. The upper skin goes into compression while the lower skin goes into tension, and a uniform bending curve will develop (Fig. 15-19b). However, this only happens if the shear rigidity modulus of the cellular core is sufficiently high. If this is not the case, then both skins will deflect as independent members, thus reducing the load-bearing capability of the composite structure (Fig. 15-19c).

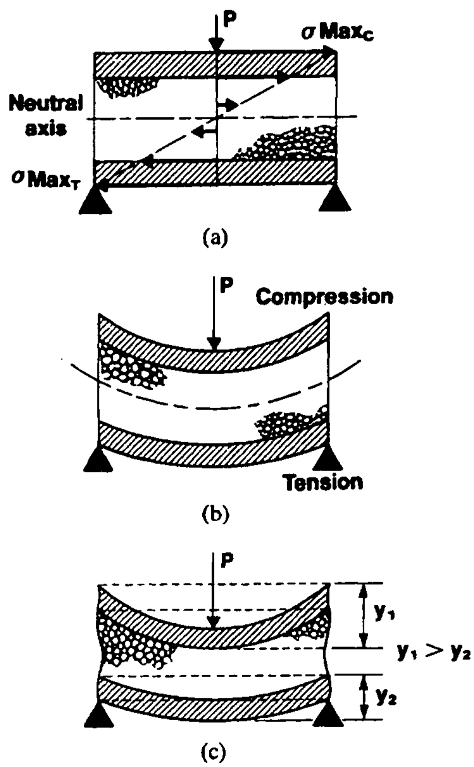


Fig. 15-19 Composite structure section of structural foam part.

The fact that the cellular core provides resistance against shear and buckling stresses implies an ideal density for a given foam wall thickness. This optimum thickness is critically important in the design of complex, stressed parts.

At a $\frac{1}{4}$-in. (6.4-mm) wall, for example, both modified polyphenylene oxide and polycarbonate resin exhibit the best processing, properties, and cost—in the range of 25% weight reduction. Laboratory tests show that with thinner walls, about 0.157 in. (4.0 mm), this ideal weight reduction decreased to 15%. When wall thickness reaches approximately 0.350 in. (8.9 mm), weight can be reduced 30%.

However, when the structural foam cross section is analyzed, its composite nature still results in a twofold increase in rigidity, compared to an equivalent amount of solid plastic, since rigidity is a cubic function of wall thickness. This increased rigidity allows large structural parts to be designed with minimal distortion and deflection when stressed within recommended values for a particular foamable resin. Depending on the required analysis, the moment of inertia can be evaluated in three ways.

In the first approach, the cross section is considered to be solid material (Fig. 15-20). The moment of inertia I_x is then equal to

$$I_x = bh^3/12$$

where b = width
h = height

This commonly used approach provides acceptable accuracy when load-bearing requirements are minimal—for example, in the case of simple stresses—and when time or cost constraints prevent more exact analysis.

The second approach ignores the strength contribution of the core and assumes that the two outer skins provide all the rigidity (Fig. 15-21). The equivalent moment of

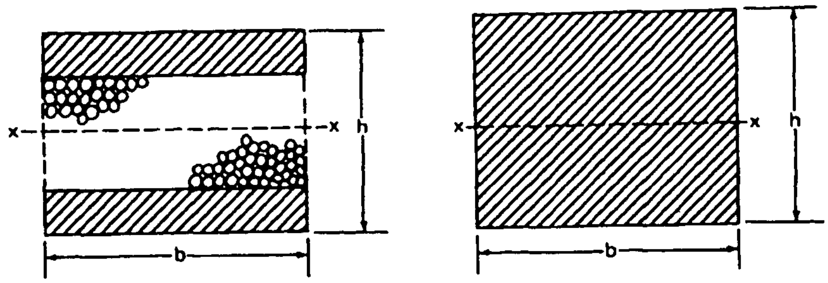


Fig. 15-20 Cross section of a solid material.

inertia is then equal to

$$I_x = b(h^3 - h_1^3)/12$$

h_1 = height of the equivalent web (core)

This formula results in conservative accuracy, since the core does contribute to the stress-absorbing function. It also adds a built-in safety factor to a loaded beam or plate element when safety is a concern.

A third method is to convert the structural foam cross section to an equivalent I-beam section of solid resin material (Fig. 15-22). The moment of inertia is then formulated as

$$I_x = [bh^3 - (b - b_1)(h - 2t_x)^3]/12$$

where $b_1 = b(E_c)/(E_s)$
E_c = modulus of the core
E_s = modulus of the skin
t_s = thickness of the skin

This approach may be necessary when operating conditions require stringent load-bearing capabilities without resorting to over design and thus unnecessary costs. Such an analysis produces maximum accuracy and would be suitable for finite element analysis on complex parts. However, the one difficulty with this method is that the core modulus and the as-molded variations in skin thicknesses cannot be accurately measured.

Blowing Agents

Blowing agents, be they solid, liquid, or gaseous substances, are used to impart a cellular structure to molded thermoplastics. The blowing agent is a source of gas that can be used by the molder to control sink marks, provide resins savings, or manufacture structural foam parts.

In general, blowing agents can be classified as either physical or chemical. The physical blowing agents include compressed gases and volatile liquids. The volatile liquids are generally hydrocarbons such as hexane or pentane as well as other aliphatic hydrocarbons. The materials act as a source of gas by changing their physical state from liquid to gas during processing. Volatile liquids have not been extensively used in foaming thermoplastics to date.

The most widely used blowing agent of the physical type is compressed nitrogen. Nitrogen is injected directly into the polymer melt

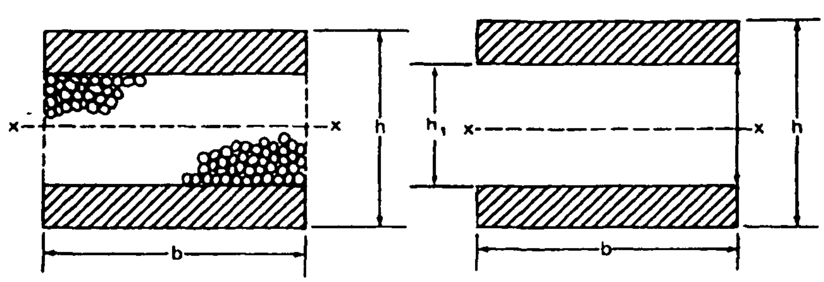


Fig. 15-21 Cross section of a sandwich structure.

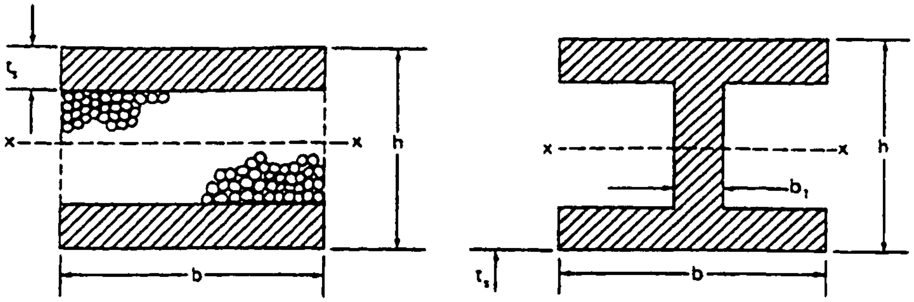


Fig. 15-22 Cross section of an I-beam.

prior to injection. Advantages of Nitrogen gas is inert, leaves no decomposition residue, and is not limited to a specific decomposition temperature range.

Chemical blowing agents (CBAs) are generally solid materials that decompose when heated to a specific temperature, yielding one or more gases and a solid residue. Chemical blowing agents also can be divided into the organic and inorganic types. The most common inorganic chemical blowing agent is sodium bicarbonate, which is being used to some extent in the production of foam parts. The major advantage of sodium bicarbonate is its low cost. The major disadvantage is that sodium bicarbonate decomposes over a very broad temperature range as compared to organic chemical blowing agents, so that its decomposition cannot be controlled as readily as that of the organic chemical blowing agents.

Organic chemical blowing agents are solid materials designed to decompose over specific temperature ranges. Therefore, the primary criterion used to select a chemical blowing agent is the processing temperature of the plastic to be foamed.

Methods of Processing SF with Chemical Blowing Agents

Injection-molded structural foam parts may be produced by both low- and high-pressure processes. In this context, low or high pressure refers to the mold cavity pressure. Nitrogen gas and chemical blowing agents are widely used in both processes.

Some of the specialized structural foam processes and equipment are patented and may require licensing. The processor is advised to ascertain the patent situation before employing any of these specialized techniques.

Low-pressure foam Injection-molded (structural) foam is produced by incorporating the selected chemical blowing agent with a resin and injecting a short shot (less than the volume of the mold cavity) into the tool. Gases released by decomposition of the blowing agent expand the polymer to fill the cavity. Since the mold cavity is not completely filled with resin, the pressure in the tool is only that generated by the blowing agent.

Low-pressure foam is produced on a variety of equipment with internal cavity pressures ranging from 200 to 600 psi (1.4 to 4.1 MPa).

Foam molding on conventional machines requires some modifications to produce good-quality parts. The most important of these is the use of a positive shutoff nozzle to prevent drooling of the expandable melt, which causes a variation in part weight as well as nozzle freeze-up. The shutoff nozzle may be mechanically, spring-, or hydraulically activated.

Although a shutoff nozzle is essential, other modifications can be made to improve part quality and increase the capacity of the machine. These include an intensifier to increase injection speed and an accumulator to increase shot size. Conversion kits are commercially available for all of the above modifications.

This approach allows the molder to convert a standard injection machine from solid to

Table 15-4 Compatibility of plastics for coinjection[a]

Materials	ABS	Acrylic Ester Acrylonitrile	Cellulose Acetate	Ethyl Vinyl Acetate	Nylon 6	Nylon 6/6	Polycarbonate	HDPE	LDPE	Polymethylmethacrylate	Polyoxymethylene	PP	PPO	General-Purpose PS	High-Impact PS	Polytetramethylene Terephthalate	Rigid PVC	Soft PVC	Styrene Acrylonitrile
ABS	+	+	+				+	–	–	+		–		–	–	+	+	0	+
Acrylic Ester Acrylonitrile	+	+		+								–			0				+
Cellulose Acetate	+		+	–															
Ethyl Vinyl Acetate		+	–	+				+	+			+		+			+	0	
Nylon 6					+	+		–	–			–			–				
Nylon 6/6					+	+	–	–	–			–			–				
Polycarbonate	+					–	+							–	0				+
HDPE	–			+	–	–		+	+	–	–	0							
LDPE	–			+	–	–		+	+	–	–	+		–				–	
Polymethylmethacrylate	+							–	–	+		–		–	0		+	+	+
Polyoxymethylene								–	–		+	–							
PP	–	–		+	–	–		0	+	–	–	+	–	–	–		–	–	
PPO												–	+	+	+				–
General-Purpose PS	–			+			–	–	–	–		–	+	+	+			–	–
High-Impact PS	–	0			–	–	0			0		–	+	+	+			–	–
Polytetramethylene Terephthalate	+															+			+
Rigid PVC	+			+						+		–					+	+	
Soft PVC	0			0				–		+		–		–	–		+	+	+
Styrene Acrylonitrile	+	+					+			+			–	–	–	+		+	+

[a] + = good adhesion. – = poor adhesion. 0 = no adhesion. Blank indicates no recommendation (combination not yet tested). The addition of filters or reinforcements leads to a deterioration of adhesion between raw materials for skin and core.
Source: Battenfeld.

foam (or the reverse) without difficulty and requires a relatively small capital investment.

Special machines, similar to high-speed two-stage injection molding machines, have been specifically designed and built for the production of low-pressure foam moldings. Typically, these machines offer the advantage of high-speed injection rates, large shot capacity, and large platens. Because of the lower clamp tonnages used, less expensive tooling is required. Both inline reciprocating screw and two-stage screw-plasticating/ram-injection units are available.

A chemical blowing agent is also used in low-pressure foam systems when compressed nitrogen is the primary blowing agent. The addition of the CBA in this process facilitates cell formation and uniformity in the molded parts.

High-pressure foam Chemical-blowing-agent-expanded products can also be made on specialized foam machines using the high-pressure technique. A full shot of expandable plastic is injected at pressures normal for the resin involved. A skin of solid plastic is formed by cooling at the mold surface, and expansion of the core occurs by moving one or more plates to enlarge the mold cavity.

This process provides a more distinct skin than the low-pressure systems, better reproduction of cavity detail, and a surface that

may be essentially free of splay if the correct combination of chemical blowing agent and processing conditions is used.

With this process, it is possible to vary density by controlling the mold expansion motion so that essentially solid sections are obtained when high strength is required and weight reduction limited to noncritical areas.

Coinjection (sandwich) machines capable of injecting both solid and foam polymers are also available. Simultaneous injection occurs, resulting in a solid outer layer surrounding a foam core. Since the solid polymer forms the exterior skin, parts have an excellent out-of-mold appearance and require little or no postfinishing operations. Different resins may also be combined in the same part to maximize cost-performance.

The multiple-component injection molding process with blowing agent allows the production of parts that are 5 to 30% lighter than compact injection-molded parts.

Processing SF with Gas Blowing Agents

A nitrogen gas blowing agent, when introduced into a molten polymer, requires specialized equipment. Such equipment was extensively developed and consists of a continuously running extruder, a gas inlet into the cylinder, one or more accumulators to hold the foam mixture, and a mold. All these are connected by suitable pipes and one or more injection nozzles, which feed the mold. The multiple-nozzle arrangement is necessary because of the limited flow length of the polymer and blowing agent mixture; it facilitates the use of multicavity molds and making of large objects.

The extruder thoroughly mixes the gas and material and feeds a prescribed volume of material and foam mixture into one or more accumulators, where it is kept under pressure to prevent premature expansion. When the proper volume of the mixture is reached, a valve opens, and a piston in the accumulator quickly forces the material into the mold. The stroke of the piston determines the volume of material delivered to the mold. The mold is only partially filled. At this point, the valve closes, and the expanding gas fills the mold and exerts pressure on the forming skin to prevent skin marks. With the high melt temperature of the polymer, rapid delivery of the material to the mold, and 25% of the circumference of the parting line devoted to equally spaced vents, a smooth surface finish can be attained (Fig. 15-23).

There are other processes either in the development stage or in use for specialized applications (Table 15-5). Most of them, including those described here, involve patents, and the owners of such patents look for licensing arrangements. The patent question is another aspect of structural foam molding that requires attention and analysis before one makes a move toward application of the system of structural foam molding.

The patented Cashiers Structural Foam with counterpressure can practically eliminate the usual swirl finish associated with low-pressure molding. In counterpressure, the cycle begins with gas pressurization of the mold cavity, followed by injection of a shot. Back pressure prevents the blowing agent from expanding until part skin forms, at which

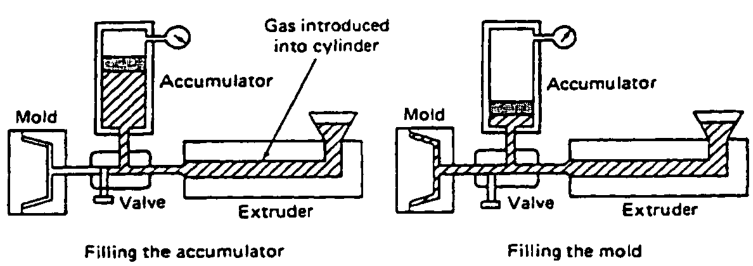


Fig. 15-23 Injection molding SF with nitrogen gas blowing agent.

Table 15-5 Some of the different patented techniques for molding structural foam

Union Carbide: Injection molding using extruder with blowing agent (usually inert nitrogen) and an accumulator. The mold cavity is "underfilled," which identifies this system as "low-pressure" (most popular, was previously patented; later patent was cancelled).
USM: System using basically conventional-type injection molding machines with expansion mold (or special mold).
ICI: Injection molding with two or more screw plasticizers to obtain integral skin; used when skin and core material can be of different materials.
Mobay (Bayer): Durometer process, in which a two-liquid-component urethane is injected into a closed mold; referred to as chemical reaction molding.
Allied Chemical: Similar system to conventional reciprocating high-pressure screw machines, except that after full-shot load enters cavity, excess material escapes from the cavity, going back into a special manifold. This excess material is reinjected during the next shot.
Phillips Petroleum: Engelit low-pressure process, which takes melted resin pellets from a revolving turntable with the blowing agent metered into an extruder/injection unit.
Cincinnati Milacron: Urethane foam that provides self-skinning, is fire-retardant.
Hoover Universal: Special screw injection machine with specially designed mold that includes venting system.
Upjohn: Isoderm process that provides for a mix of two-part isocyanite materials.
Rubicon Chemicals (jointly owned by ICI and Uniroyal): Rubicast process that uses special integral skinning urethane foam.
Marbon: Use of ABS for expansion casting.
Hercules: Use of polypropylene bead with blowing agent for application in processes other than injection.

time it is vented, and expansion fills the mold 100%.

Another important patented process, by Hoover Universal and Union Carbide, is called the structural-web molding technique. The structural-web process is so named because of the part's interior configuration. The idea behind the process is to inject gas into a molten polymer in the mold such that the gas–polymer interface is deformed into a wavelike corrugation, using the principle of the hydrodynamic instability of viscous fingering. The structural-web process has molded such parts as painted tote boxes. It clearly has potential for applications in which a high strength-to-weight ratio is desired. Economy of material recommends it for other applications.

The process consists of these steps:

- Passing molten plastic material into a mold cavity until it is partially filled
- Injecting pressurizing gas (usually nitrogen) into the melt
- Coordinating the gas-injection rate, pressure, and other variables so that the gas–polymer interface is deformed into a wavelike corrugation, and the movement of the gas–polymer interfacial flow front is divergent
- Maintaining a positive pressure inside the part until it is self-supporting
- Releasing the gas pressure so pressure inside the part is reduced to atmospheric pressure
- Removing the molded structural-web part from the mold

Allied Chemical has a high-pressure patented injection molding process for producing structural foam. In this process, a standard injection molding machine is used with a specially designed mold. Plastic melt is permitted to egress from the fully packed mold, and thus the pressure within the mold is reduced, allowing foaming to occur.

The Allied Chemical patented structural foam process operates as follows: (1) The reciprocating screw has just advanced and filled the mold with polymer under full pressure; (2) after the skin of desired thickness has formed, the screw retracts, reducing the internal mold pressure as the excess melt egresses back into the manifold and plasticator cylinder; (3) as soon as the desired degree of foaming has occurred in the core of the molding, polymer egression is stopped by runner cylinders advancing to close off the egression ports; and (4) in the last step of the process, the molded part is removed from the mold.

Tooling

For low-pressure foam applications, molds can be less expensive because of the lower clamp forces used. Molds for low-pressure foam systems may be constructed from forged aluminum, supported cast aluminum, Kirksite, or steel. For foam molding on high-pressure systems or modified conventional machines, steel molds are used because of the high clamp tonnages utilized. It is not recommended that Azodicarbonamide (Azobisformamide) be used with beryllium–copper molds because of corrosion caused by prolonged runs with this blowing agent. Chrome plating of beryllium–copper molds has been used to reduce the degree of corrosion, but this has not proved to be the ultimate solution.

Molds should be designed for efficient cooling when molding foams to minimize cycle times. This is especially important when the part has thick sections.

The adequate venting of mold cavities is essential to allow excess gas to escape and enable complete filling of the mold as the plastic expands. Inadequate venting will result in unfilled parts and can also cause "burning" of the part in the vent area.

Usually, vents from 0.005 to 0.010 in. (0.013 to 0.025 cm) are suitable, but actual experimentation with the mold using metal shims should be done to determine where vents should be placed and what their depth should be.

Sprues, runners, and gates are usually made as generous as possible but should not be so large as to cause an increase in cycle time or the amount of regrind generated.

Sprues are usually tapered (going from the machine nozzle to the tool) to help minimize expansion of the melt. Length should also be kept to a minimum so as not to interfere with cycles.

Runners should be generous to allow for fast injection rates. Care should be taken, however, that runners be designed so that pressure will be maintained on the melt to prevent expansion. Runner systems for multicavity molds should be designed so that fill rates to each cavity are balanced.

Gates should be sized so that fast and complete fill of the part is facilitated. Usually, the width and thickness of gates are both smaller than part thickness. This provides easy removal from the molded part, and no interference with cycle times occurs.

Whenever possible, gating of a foam part should be in the thinnest area. This allows the low-pressure melt to flow more easily into the thicker sections of the part and ensures that thin sections will be completely filled.

Start-up for Molding

Over 98% of all structural foam molding to date has been with the low-pressure techniques, and it is likely that the major technique will continue to be low pressure (Chap. 2, Start-Up and Shutdown Operations).

Factors to consider when molding low-pressure foamed parts are as follows:

1. Injection pressure should be set high enough to enable the maximum injection speed obtainable. High-speed injection provides improved surface quality. Back pressure should be used [100 to 200 psi (0.7 to 1.4 MPa)] for consistent, even filling during plastication. Screw speeds of 20 to 50 rpm are normally used.

2. Shot size should be adjusted to approximately 25% less than cavity volume. Note: Shot-sizing setting should be such that the screw completely bottoms out during injection, that is, no cushion is used.

3. Processing temperatures should be chosen that are consistent with the polymer and blowing agent being used. An increasing profile is preferred, with the rear zone temperature set lower than the decomposition point of the blowing agent. This ensures that blowing agent efficiency will not be lost by degassing through the hopper.

4. Mold temperatures affect surface finish, skin thickness, and cycle time. Hot molds will yield a more glossy surface, thin skins, and longer cycle time. Cool molds, in contrast, yield a duller finish and thicker skins with shorter cycles. Mold temperatures will

normally range from 60 to 140°F (16 to 60°C), but higher or lower temperatures are not uncommon. It is sometimes advantageous to include both heating and cooling channels in the mold to obtain an improved surface (heating) and short cycle times (cooling). Quenching the part in water immediately upon demolding may also be helpful in reducing postexpansion and cycle times. This is particularly true for molded parts containing thick sections, which would require a long cooling cycle.

5. Cycle times typically range from 60 to 120 sec but are dependent on the polymer being formed, part thickness, and mold temperature.

6. Venting should be determined by experimentation with the mold, using metal shims before cutting the mold.

Injection–Compression Molding (Coining)

Injection–compression molding (ICM) also known as coining or injection stamping is a variant of conventional injection molding. The essential difference lies in the manner in which the thermal contraction is compensated in the mold cavity during cooling (shrinkage). With conventional injection molding, the reduction in material volume in the cavity due to thermal contraction is compensated by forcing in more melt during the pressure-holding phase. By contrast, with ICM, one uses a compression mold design in which a male plug fits into a female cavity rather than the usual flat surface parting line mold halves used for injection molding (1, 7, 13, 22).

The melt is injected into the cavity as a short shot and hence does not fill the cavity (Fig. 15-24). The melt in the cavity is

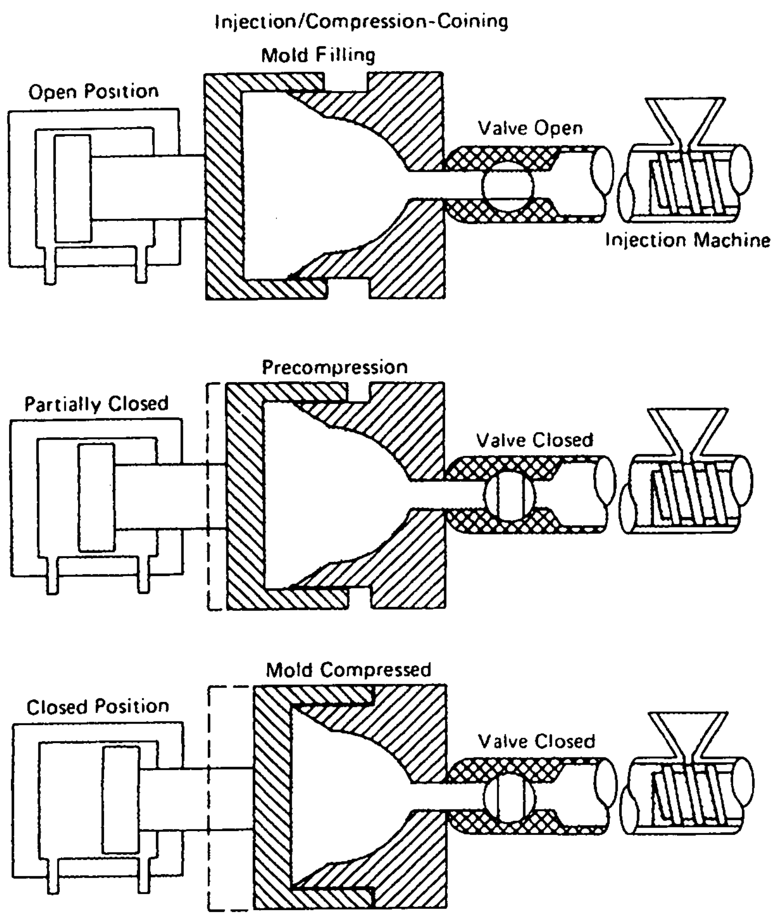


Fig. 15-24 The coining operation combines injection and compression molding.

essentially stress-free since it is poured into the cavity. Prior to receiving melt, the mold is slightly opened so that a closed cavity exists; the male and female parts are slightly engaged, as in a compression mold action, so the cavity is partly enclosed. After the melt is injected, the mold automatically closes based on the machine's operating settings and this produces a relatively even melt flow. With this controlled closing, a very uniform pressure is applied to the melt. Sufficient pressure is applied to provide a molded part without stresses. This type molding offers many advantages for enhancing molded part performances.

ICM can provide a repeatable stress-free molding or, if desired, very little controllable and even internal stress. ICM also minimizes warpage, allows moisture and gases to escape with ease, and facilitates uniform flow in complex mold cavity. Conventional IMMs can be modified to provide the action required by the mold. Usually they are all electric converted IMMs (Chap. 2).

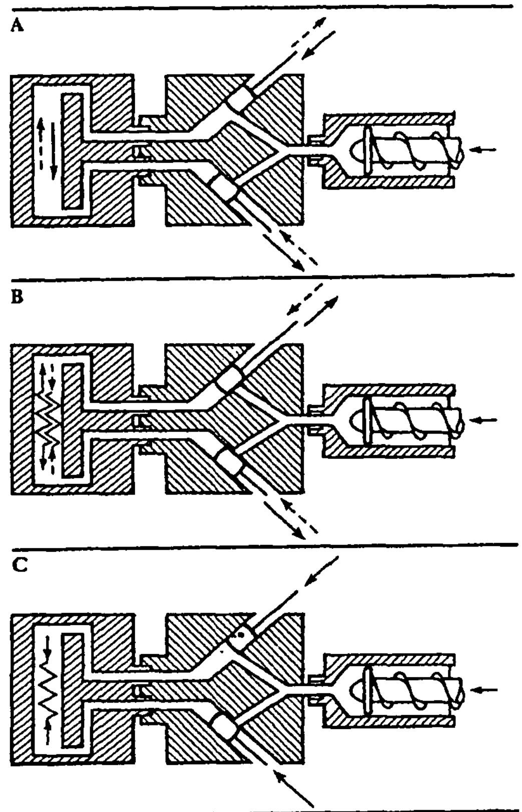


Fig. 15-25 Multiline injection molding uses two alternating melt streams entering the cavity.

Multiline Molding

The patented Scorim process is a molding method to improve strength and stiffness of parts by eliminating weld lines and controlling the orientation of fibers. A conventional injection molding machine uses a special head that splits the melt flow into two streams (Fig. 15-25). During the holding stage, two hydraulic cylinders alternately actuate pistons above and below the head, compressing the material in the mold in one direction and then the other. This aligns the fibers, removes weld lines, and induces orientation in liquid crystal polymers (LCPs). Used with thermoplastic and thermoset plastics, this process is similar to the push–pull method (British Technology Group, USA, 2200 Renaissance Blvd., Gulf Mills, PA 19406).

Counterflow Molding

With conventional thermoplastics injection molding, the melt is injected from the injection unit into the cavity of the closed injection mold via a sprue bushing and the attached runner system. After the cavity has been filled, shrinkage is eliminated by means of holding pressure and the introduction of additional melt, after which the molded part solidifies during the cooling time until ejection takes place.

The same approach in the filling and holding pressure phases is employed in multishot and multicolor injection molding with two or more injection units, in which case a special rotary mechanism in the mold transfers the initially molded parts into the cavities for the final molded parts.

Since plasticated material is injected into what is essentially a closed cavity in classical injection molding, considerable injection pressures and correspondingly high mold clamping pressures are sometimes required, depending on the molded part design, to

achieve dimensionally accurate molded parts with good properties.

The principle of counterflow injection molding employs the machine technology of multishot injection molding with appropriately modified control electronics. In a complete reversal from the conventional approach, the mold is so designed with two or more runner and gating systems. Two injection units are used. One can directly melt through a conventional sprue or runner. The second injection unit moves melt through a different sprue or runner, which is in the opposite direction of flow from the first unit, or from the opposite side of the cavity. Because the melt can now flow through the cavity, the filling process can be influenced in a much more specific manner than previously. In the course of filling the cavity, the plasticated material flows from the primary to secondary injection unit.

In doing so, the melt is under a defined and specified pressure, which can be set and controlled exactly by the difference between the hydraulic pressures acting on the two screws. During the injection molding process, the primary screw moves toward its associated sprue bushing, whereas the secondary screw moves away from its associated sprue bushing. By exchanging the data for direction and pressure, this flow-through phase can be matched to the particular requirements and repeated as often as necessary. After the filling phase, the axial motion of each screw is stopped and the holding pressure to eliminate shrinkage is generated by applying a defined pressure to the primary and/or secondary screw. The cooling phase and ejection now follow as in a conventional injection molding cycle.

The flow of melt through the cavity in such a manner that it leaves the cavity again represents a modification of the part-formation process, which can be employed to introduce specific orientation and fiber alignment. During fountain flow into the cavity, the lateral expansion of the melt at the flow front creates thin biaxial blank and marginal layers that are immediately frozen along the cavity wall. These are also oriented somewhat—with LCPs—in the direction of flow. Below the marginal layer, in the zones with the greatest increase in velocity, the melt is subjected to high shear stress in the direction of flow and the fiber packets are aligned parallel to the action of the shear field (shear layers). Up to this step in the cycle, both injection molding processes are identical.

With conventional injection molding, the so-called core layer is now formed during the subsequent packing and holding phase. The layer-formation phase is characterized by orientation processes resulting from the decrease in shear to zero toward the center of the molded part. Shear displacement inward is, in part, responsible for the formation of additional layers oriented in the direction of flow contiguous to the original shear layers. Because of the cooling processes in the interior of the molded part and with slower movement of the melt, coarser-fiber structures can sometimes be formed with LCPs. The actual melt core in the center of the molded part, which becomes oriented with the introduction of additional plasticated material into the cavity under holding pressure, shows in its frozen structure—especially for LCPs with their slight tendency for relaxation—a strong dependence on the flow geometry as well as on gate position and design.

Oscillatory Molding of Optical Compact Disks

An oscillatory molding technique is a method used for making optical compact disks. Optical disks use laser light to read digital information stored on the surface of a substrate. Light passes through the substrate twice as it reflects off the information, which is typically on the order of a submicron spot. Optical path difference, or birefringence, needs to be minimized to assure that light will focus on a small spot and remain focused as it returns to the sensor.

Compact disks (CDs) use normal incident light reflected from pits (0.1 μm deep) molded into the plastic substrate during the injection molding process. The pit side of the substrate is subseqently metalized with

aluminum or gold, which, in turn, is spin-coated with a polymer to protect against physical damage. Billions of pits are molded into the substrate in a spiral pattern. The ultimate quality of this disk format depends on the precision of the pits and level of optical distortion introduced by the polymer substrate. The sputtering of a 400-Å reflective film on the pit side of the substrate is generally not a major problem.

Rewritable disks are not commercially available with polycarbonate substrates. Several different technologies for data storage have been under development, with magneto-optical (MO) the front runner. This technology coats a transparent substrate that is nearly birefringence-free with a 20-μm-thick alloy (amorphous magnetic layer). Both materials and processing steps contribute to the total birefringence. Even though material systems can be developed with very low levels of birefringence, orientational birefringence and surface stress, along with thermal stress birefringence, develop when these materials are injection-molded. Oscillatory molding offers a means to circumvent these problems.

Conventional injection molding is characterized by strong shear and extensional flows with nonisothermal boundary conditions. Velocity gradients in these flow fields orient the polymer chains. The orientation produces anisotropic properties in the molded part. The nonisothermal boundary conditions at the cavity walls of an injection molding generate thermal stresses as the polymer cools, which in turn produces birefringence.

One approach to reducing birefringence in plastic disk substrates has been to physically mix or blend two polymers with opposite orientational birefringence behavior such as PS and PC. However, this approach does not reduce the thermal contribution. To minimize birefringence in a molded disk substrate, the polymers and process physics need to be considered together. Since orientational stress contributes heavily to the overall level of birefringence, processing techniques for altering chain orientation and reducing entanglements have the potential for pro ducing significant improvements in optical properties.

A novel disk mold with a movable cavity wall has been used to reduce birefringence. The cavity measures 52 mm in diameter and is 1.85 mm deep with a centrally located sprue gate on the stationary side of the cavity. The moving cavity wall opposite the sprue can be rotated at a constant speed or oscillated at a fixed frequency and amplitude. Two different linear bis-phenol A polycarbonate resins were molded, with low and high molecular weights.

All frequencies were relatively low, but the best results were obtained at the high end of the range, 0.73 cycle/sec with an amplitude of 65 deg. The optical retardation (a measurement of the directional dependence for the transmission of light) in the molded disks (substrates) was measured at three different radial locations (7, 14, and 21 mm). Both normal incident light and 30° off-normal incident light were used to characterize the optical properties. The birefringence was computed by dividing the retardation value by the disk thickness (1.85 mm).

The surface strain was measured by mounting bidirectional strain gauges on the surface of the disks at two radial positions and then annealing the disks above 130°C for various lengths of time (hours). Even at relatively low oscillations, 0.73 cycle/sec, retardation is reduced for normal incident light and 30° off-normal incident light. This relatively small disruption of diverging radial flow field has a dramatic effect on the resultant orientation and entanglements. In general, orientational stresses affect normal incident light retardation more, whereas thermal stresses have a greater effect on the 30° off-normal retardation. Since both retardation mechanisms are affected by a moving wall, it can be inferred from the results that the entanglement density of the network has been reduced.

Digital Video Disk Moldings

IMM manufacturers worldwide are actively engaged in providing equipment for the growing digital video disk (DVD) market. For example, there is the all-electric Ferromatik Milacron with programmable coining

(injection–compression molding) capability (Chap. 2). These developments follow along the footpath of CDs. Many of the IMMs manufacturers that focus on video, audio, and data-storage devices have coining capability. Just over a decade ago, CD moldings had total disk capacities of less than one GB (gigabyte) per square inch. At present they can hold up to 20 GB (82, 424, 443, 525).

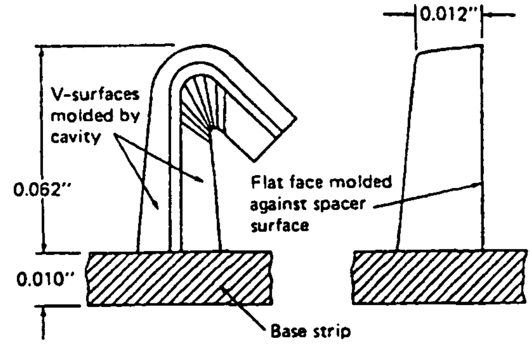


Fig. 15-26 Size and shape of Velcro spines.

Continuous Injection Molding

Machines to injection-mold parts using continuously operating extruders have been designed, built, and used in different major production lines. [Note that an injection molding machine is simply an extruder that operates in a noncontinuous fashion (3).] The extruders are continuous melt processors. They melt the plastic and utilize various techniques to delivery the melt into mold cavities. These continuous screw rotating machines use many molds. The molds are usually located on a rotating circular table that can operate as Ferris wheels and carousals. Feeding a melt (through special nozzle adapters to the contour of the molds) onto a rotating mold is not a new concept, having been applied since at least the 1940s. Products made with this technique include Velcro strips, miniature snap-in plugs for telephone wires, small containers for photographic film, shoe soles, sandals, boats, and so on.

Velcro Strips

Velcro strips can be manufactured with a continuous injection molding operation. The major pieces of equipment needed are a conventional extruder and a rotating Ferris wheel mold. The equipment can be set to mold the strip from the plastic, trim it, condition it for flatness, apply an adhesive backing, and wind it on a reel (Chap. 17, Markets, Velcro for Flexible Packaging).

In one approach the Velcro fastener consists of two mating strips (Fig. 15-26), one strip covered with nearly microscopic hooked or barbed spines, the other with tiny loops. When the two strips are pressed together, their projections become entangled to produce the gripping action.

Peeling the strips apart deflect the spines, disengaging them from the loops. Because of the resilience of the materials, the projections snap back to their original geometry so that the strips can be used repeatedly.

For years Velcro had been made by a slow, complex textile process in which the loops are woven through the back of a flexible base strip; for the male strip, the loops are cut to create the hooks. Seeking a more economical alternative, Velcro USA (Manchester, NH) engineers wondered if the fastener could be produced by injection molding the projections' integral with the base strip in a single, continuous operation.

Foster-Miller Associates, Waltham, MA, which specializes in designing and building one-of-a-kind machines, took on the project of developing equipment to mold the male half of the Velcro system. The engineering firm subsequently received a patent (assigned to Velcro USA, Inc.) on the resulting molding machine.

A few details about the fastener will underscore the formidable molding problems that the designers had to solve. The spines are almost too small to see: They project about $\frac{1}{16}$ in. (0.16 cm) from the 0.010-in. (0.03-cm)-thick base strip, are 0.020 in. (0.05 cm) wide at their base, and taper to about 0.012 in. (0.03 cm) at the tip (Fig. 15-26). They are very closely spaced, on approximately 0.050-in. (0.13-cm) centers; a single square inch of the strip contains more than 250 of these projections. Moreover, they are not simple,

needlelike shapes but are rectangular in cross section and have a microscopic hook or other type of barb at the tip. Dimensions must be held to 0.0015 in. (0.004 cm) and no flash is permissible anywhere on the strip.

Molding technique The molding line developed by Foster-Miller produces Velcro in a continuous process. The equipment molds the strip from the resin, trims it, conditions it for flatness, applies an adhesive backing, and winds it on a reel.

The key elements are an extruder and a rotating Ferris wheel mold. The extruder runs continuously, feeding the melt into the continuously rotating mold through a special adapter mounted on the extruder-barrel outlet. The 2-ft (61-cm)-diameter mold turns at about 10 rpm, delivering Velcro at 60 to 70 ft/min (18.3 to 21.3 m). The extruder is basically standard; the most innovative features of the installation are the rotating mold and adapter.

What makes this installation so unusual is the precision of the product and ingenuity of the mold. The mold contains more than 15,000 cavities less than $\frac{1}{16}$ in. (0.16 cm) deep and arrayed less than $\frac{1}{16}$ in. apart in parallel rows around its circumference (Fig. 15-27a).

Besides the task of designing a tool to mold the Velcro, the design firm had to figure out how to strip it from the mold. Remember that each spine has a hook or other projection that must be disengaged without damage from the undercut at the base of its cavity as the strip is being peeled from the mold (Fig. 15-27b).

The engineers at Foster-Miller devised a wheel-shaped mold consisting of several dozen, thin [(0.060-in. (0.015 mm)], round plates bolted together. The plates are of two types, which alternate across the thickness of the "wheel." One, the cavity plate, contains a ring of molding cavities for the projections on both sides of the plate at its outer edge. Between each cavity plate is a blank spacer plate. Being in intimate contact with the cavity plate, the spacer plate acts to seal off the open side of the cavities. The set of alternating spacer plates is designed to slide in and out (radially) as a group; the cavity plates have no radial motion. During most of the cycle, the spacer plates are extended to the full diameter of the mold so that their edges line up with those of the cavity plates. This alignment creates the flat surface that molds the inner face of the Velcro strip (Fig. 15-28).

Injection process As the mold rotates past the injection head, the melt is injected onto the circumference of the mold and forced by the injection pressure into the cavities.

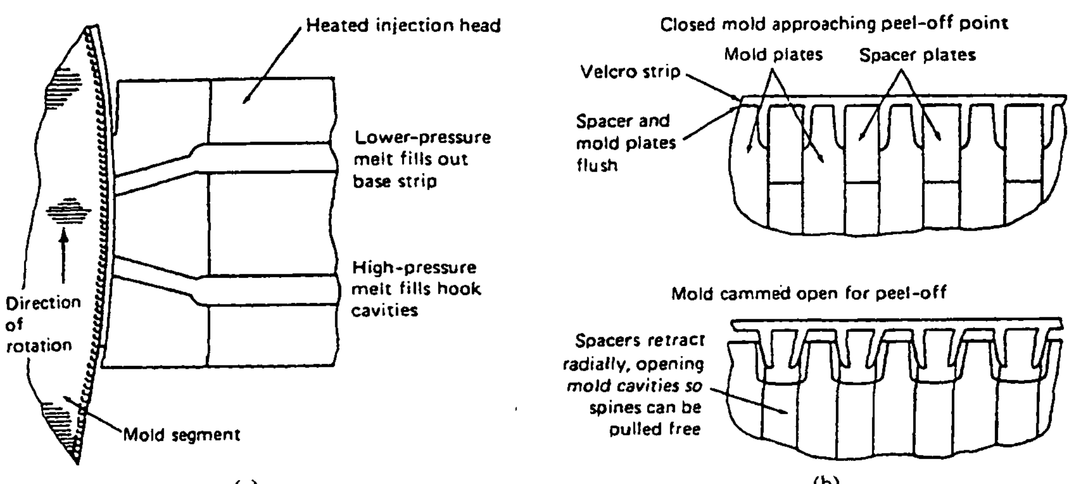


Fig. 15-27 Molding Velcro. (a) Two orifices feed melt onto a rotating mold. (b) Method used to peel Velcro strip from the mold.

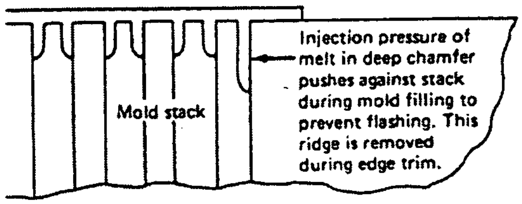


Fig. 15-28 Built-in "melt piston" compresses mold cavity.

Enough additional melt is supplied to create the base strip at the same time.

By the time the mold has completed about one-half a revolution, the plastic has solidified and cooled. At that point, the spacer plates are pulled down by a circular cam.

The effect is like a piano keyboard with every other key pushed in. The retracted plates open up the sides of the cavities to give the spines room to deflect outward and release from the cavity undercuts as the Velcro strip is pulled off the mold by the winder. After passing the peel-off point, the spacer plates move back out to their original position (Fig. 15-29).

Multiple separately mounted segments, each individually free to move radially, make up each spacer plate. For manufacturing convenience, the cavity plates likewise are constructed from individual segments. To make electrodes of such small size and high precision, Foster-Miller had to develop special techniques. Company engineers decline to describe the process beyond saying that it consists of several steps and the working electrodes are made by electro-forming.

Because of its complicated construction, the mold is cooled externally. Mold temperature is controlled by an air plenum located about one-quarter of a revolution before the injection point; the molded Velcro itself is cooled by another plenum ahead of the strip-off point. Airflow is adjusted to keep the nylon sufficiently warm and flexible so that the projections can pull free from the undercuts in the cavities without damage during strip-off.

The injection head that delivers the melt to the mold has a concave face with the same curvature as the periphery of the mold. The head is mounted on the extruder and separated from the mold face by a gap equal to the thickness of the base strip (about 10 mils).

The injection head contains two orifices, each fed by a separate gear pump. The lower

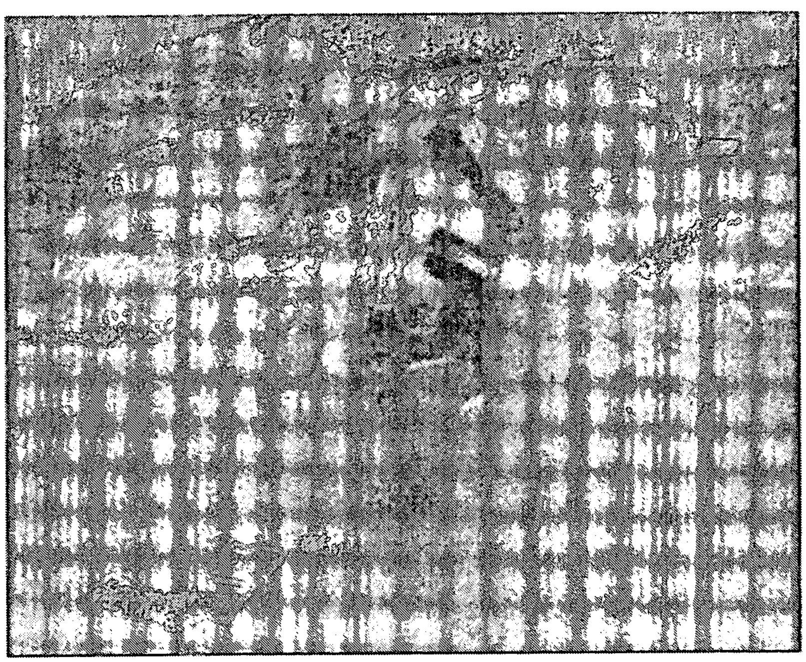


Fig. 15-29 Rotating mold to produce Velcro strips continuously in a specially designed injection molding machine.

orifice, which fills the projections, operates at a relatively high pressure (equivalent to a typical injection pressure in a closed mold) to force the melt into the blind cavities. The second orifice, just above, supplies additional melt at lower pressure to fill out the base strip.

The clearance between the injection head and mold, which determines the strip's thickness, is set by a fine gear-reduction drive and measured by four air-gauge sensors, one at each of the four corners of the head to ensure perfect parallelism. A 1-mil error in the 10-mil gap can result in as much as a 50% variation in injection pressure.

Cartridge heaters in the head maintain the melt at the proper viscosity for injection; temperature control is within ±5°F (±3°C).

The sides of the gap between the injection head and mold are not enclosed. Seepage is prevented by a careful balance of melt temperature, mold temperature, injection pressure, and mold velocity. The as-molded edges are, of course, uneven, but the edges are squared off by trimming the strip in a downstream operation after conditioning.

One of the most critical requirements in the mold design is preventing flash. Foster-Miller used two approaches to avoid this problem. One was to control the geometry of the mold plates to extremely close tolerances. Every plate in the mold stack is surface-ground to be flat within 0.002 in. (0.005 cm) across its 2-ft (61-cm) diameter. Also, plate thickness, which determines the spacing between adjacent rows of spines as well as the quality of the seal between adjacent plates, is controlled to within 0.0001 in.

The second strategy against flashing is to prevent the edges of the mold plates from flexing outward as the melt is injected into the cavities. To supplement the tie-rods through the molds, Foster-Miller devised a simple way to resist potential flexing. The melt itself is used to supply a hydraulic squeezing action on the mold stack (Fig. 15-29).

At the outermost mold plate in the stack and beyond the nominal width of the strip, Foster-Miller cut a deep chamfer around the edge of the plate. As the mold is being filled, the pressurized melt also flows into this chamfer. The resulting sidewise force against the side of the plate tends to compress the mold stack and prevent the plates from spreading.

Another key to reliable production is ensuring trouble-free radial movement of the spacer segments during mold opening and particularly during closing. Any significant galling or binding between spacers and mold plates could prevent the spacers from returning to their "home" position, flush with the edges of the mold plates. The resulting offset would produce thickness steps across the base of the Velcro strip and probably flashing as well. The engineering firm avoided this problem by applying a low-friction coating, in the form of an internally lubricated polymer, to the sliding faces.

Electrically Insulated Buttons for Coaxial Cables

Injection molding machines have been used to mold polystyrene plastic molded "buttons" (rather than a plastic foam insulation) continuously inline around the core of a thin wire. This construction is then jacketed to complete the required cable. These precision molded buttons are approximately $\frac{1}{2}$ in. in diameter, about $\frac{1}{16}$ in. thick, and accurately spaced $\frac{1}{2}$ in. apart (Fig. 15-30). The operation is completely inline starting with

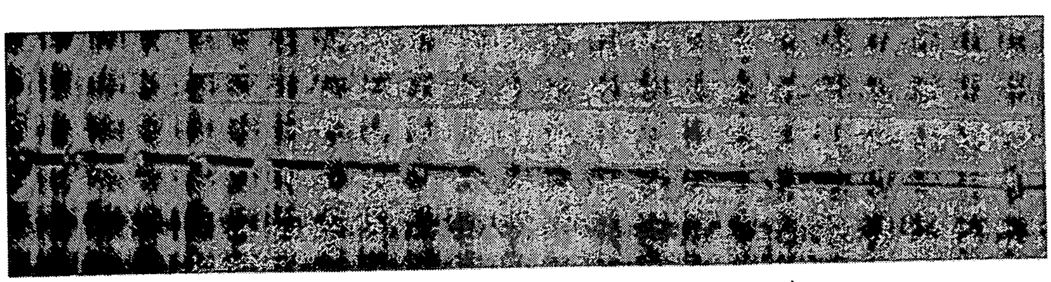


Fig. 15-30 Example of plastic buttons molded on a wire.

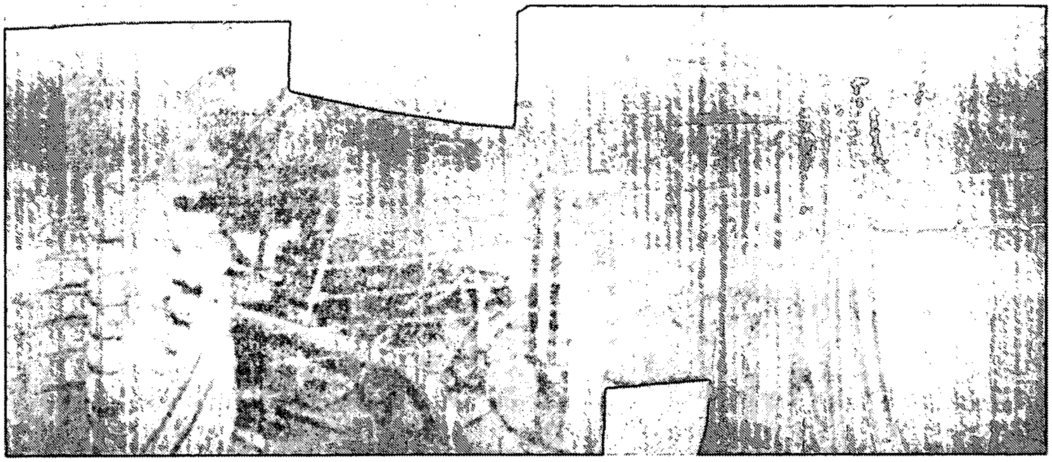


Fig. 15-31 View of the mold in the open position showing molded buttons on wires that have just been molded as they travel to the left.

at least six separated thick wires that are drawn (pulled) through mechanical draw-down tools to form the thin wires. These wires, traveling at about 1 ft/s go through an open injection mold. The IMM is on a platform that travels at the speed of the guided wires during the molding cycle. The platform follows a rectangular path. When buttons have to be molded, the mold is in the open position and moving with the wires. Upon the start of the mold closing, the platform moves slightly perpendicular to the motion of the wires so that the mold closes evenly around the wire centers (Fig. 15-31).

The IMM and wires travel about 6 ft during the complete molding cycle. The mold opens and again simultaneously moves perpendicular so that the buttons are not in contact with either halves of the mold. Immediately the platform then moves the IMM back to the starting point so it can continue to mold buttons. Using proper motion control of the platform in conjunction with guiding the wires in and out of the IMM, the precision spacing between the last button molded and the first to be molded can be achieved.

Railtrack Molding

Railtrack molding involves the continuous operation of a moving mold in a carriage. The setup resembles an elliptical railroad track system (Fig. 15-32), which provides a means to operate one IMM with a multitude of molds capable of handling materials requiring long curing or cooling cycles. The materials include glass-fiber reinforced TS plastic molding compounds, in-mold reinforced fabric TS or TP laminate constructions, and TPs requiring long curing time with or with post curing and annealing.

The IMM moves on its own tracks, while clamping carriages, each containing a mold under the required clamping pressure and mold temperature control, travel around the elliptical tract (Fig. 15-33). An electrical third rail (as in an electrically operated train) provides the power (to heat or cool mold, etc.). A programmer interfaces all the required actions that have to occur during the complete molding cycle for the IMM and all the molds.

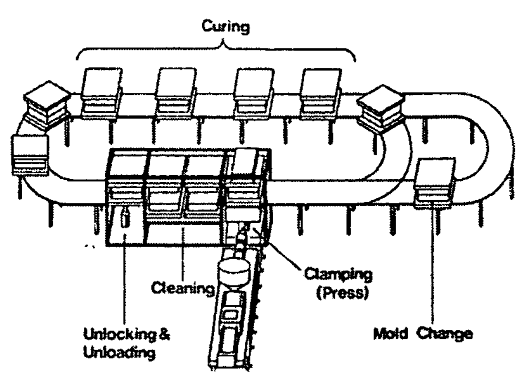


Fig. 15-32 Schematic of the IMPCO Trak molding machine.

Plastics World

June, 1994

SECTION: Vol. 52 ; No. 6 ; Pg. 49; ISSN: 0032-1273

LENGTH: 3368 words

HEADLINE: The productivity race is on; blow molding; includes related articles

BYLINE: Schut, Jan H.

BODY:

Bring a stop watch and calculator to time machine cycles per cavity, the scan times of PLC controls, quick mold changes and lots of downstream automation

Blow molding machine makers will bring a lot of machines and processes to the NPE in Chicago this month that are new for the U.S., new for their company or new for NPE, though many were already shown at Kunststoff '92 in Dusseldorf or other major shows. There will be a few new machines, large and small, that were never shown anywhere before. And from the biggest accumulator head machines to the smallest container blow molders, displays will feature new-generations of machine controls and process monitoring, plus novel downstream equipment for automation and quality testing.

In bottle machines the big news is the arrival of European "long-stroke" extrusion blow molders with high cavitation and relatively slow cycle times. While new here, they were all at K '92, and a few are even operating here. Four make shampoo bottles in Puerto Rico, for example.

In industrial blow molding, a display to catch is the first U.S. demonstration of dual durometer coextrusion blow molding and flashless parison manipulation. Krupp Kautex of Germany (represented in the U.S. by Krupp Plastics & Rubber Machinery, Edison, N.J.) will use both to make an automotive duct. But both techniques have been seen before. Johnson Controls Inc., Manchester, Mich., demonstrated dual durometer coextrusion at K '92. And Battenfeld Blasformtechnik GmbH in Germany (with U.S. offices in Boonton, N.J.) showed a combination of flashless and dual durometer blow molding last year at Interplas in Birmingham, England.

Diff'rent strokes for extrusion blow molders

Long ones, to be exact. So called "long-stroke" extrusion blow molding machines will be introduced to the U.S. at NPE. Battenfeld, Krupp, and Techne of Italy (affiliated with Techne Graham in York, Pa.) will all have machines running on the floor. All showed them first two years ago at K '92. Long-stroke blow molders have extended, extra-wide platens for up to 10-15 cavities, compared to 4-6 cavities per shuttle for a normal one- or two-sided shuttle

machine. "Long stroke" refers to the long way this wide-bodied platen has to travel to pick up parisons.

Long stroke machines are expected to compete directly with high-cavitation, reciprocating screw blow molders, the so called "dairy bottle" Uniloy machines from Johnson Controls Inc., which also go up to 12 cavities, as well as with conventional shuttles. Compared to the recip screw, the long-stroke takes less floor space and gives more flexibility, according to Joe Spohr, vice president and general manager of Techne North America in York, Pa.

It's also "easier to make better bottles" on a long-stroke machine because it cycles more slowly than conventional shuttles, says Dane Belden, president of Battenfeld in the U.S. "Handleware is easier because of higher clamp tonnage capabilities and better pinchoff." Output is probably a little higher too, Belden says, because the long-stroke has a lower scrap rate. Long stroke machines "afford better control, lower friction heat, and therefore lower melt temperatures, enabling better parison control (than conventional shuttles)," adds Techne Graham's Spohr.

New recip screw and shuttle developments

As to the recip screw machines, Johnson Controls will display its Liberty style recip-screw model at NPE for the first time. Liberty machines are made by Plastics USA Corp., Williamston, Mich., a company started some six years ago by former Uniloy people, which merged two years ago with Johnson Controls. A new Liberty RSI-3500 with three heads and a 3.5-inch extruder will blow 2.5-gallon water bottles at the show. Liberty built the first RSI-3500 six months ago for export; this is only the second. A new development on the RSI-3500 is its "bottom blow" configuration, blowing a parison upwards into the mold. Up parisons are generally found only on a few continuous wheel machines. Where Johnson Controls' own Uniloy recip-screw machines make bottles from eight ounces to 1-6 gallons, this Liberty line makes 2-5 gallon containers.

There are new shuttle machine developments too. The first of a large new machine with very high cavitation that may be a match for the long stroke is being built by Bekum in Germany (with U.S. offices at Bekum America Corp., Williamston, Mich.). It's a new model, BM 704, single- or double-sided shuttle with coextrusion. Like the long stroke, the 704 has very large platens and very high (22.5 ton) clamp force. It has a mobil clamp section with a unique closing design, previously shown at K '92. It can have up to five-parisons with 100 mm center distances, for double-sided production of a 32-ounce bottle in 10 cavities. Four single-sided versions are being built for the U.S. now to make handleware bottles, but they weren't ready in time for the show.

Other news in extrusion blow **molding**

A smaller new extrusion **blow molding** machine that you **definitely** didn't see at K is the first ever from Jomar Corp., Pleasantville, N.J. Previously exclusively a maker of injection blow molding machines, Jomar opened a new manufacturing facility in Italy on March 1, and built its first extrusion blow molding machine there. The new EBM 1.55 (for 1.5 liter containers, single-station) was shown first at the plastics show in Milan in May, then packed up and flown to NPE. The EBM 1.5S has a four-ton clamp, two-inch extruder with 25:1 L/D, 20-hp d-c drive, Bosch proportional hydraulic valves and Moog

64-point parison control. It can mold two containers with 50-mm centers or three containers with 11-mm centers.

A notable first-time-exhibitor at NPE is extrusion blow molding machine maker B & W Kunststoffmaschinen Handelsgesellschaft mbH (represented in the U.S. by FGH Systems Inc., Denville, N.J.), which will show a two-sided shuttle machine. The BW 5000 DE has new closed-loop Moog TMC machine controls and proportional hydraulic machine movements. It will also show automatic deflashing and oriented bottle takeoff. B & W is a seven year old German machine maker that began by rebuilding old Bekums and then launched its own line of shuttle and continuous extrusion machines.

A completely redesigned shuttle line from Automa SpA from Italy (represented in Canada by Moldpro in Toronto) will also be introduced in the U.S. Automa's Plus machine line, which debuted at K '92, hasn't been shown in the U.S. before. An AT-2D (double-sided) shuttle will run at the show. Automa's Plus line features new Siemens controls and proportional hydraulic mold closing (three speeds in, two out), replacing a mechanically cushioned mold close; d-c drives replace hydraulics; and tie-bar carriage replaces a track and bed.

For extrusion blow molders of custom cosmetic bottles, a new coex head is coming from Europe that puts a super thin gloss layer of nylon and adhesive on a high density polyethylene (HDPE) bottle. Nylon coextrusion is commercially used here, but as an inner layer for gas barrier properties in car gas tanks, for example. In Europe it's beginning to be used as a coating for appearance. Gas barrier helps coincidentally by keeping expensive perfumes in cosmetic products. The head is from Willi Mueller KG in Germany (represented in the U.S. by Meredith-Springfield Associates, Springfield, Mass.). It puts half a thousandth of an inch (0.0005) of nylon and half a thousandth of adhesive onto aHDPE bottle, so thin it doesn't disrupt using regrind in the bottles, Meredith-Springfield says. Flow channels in the head have special heat control modifications to handle the nylon, which processes about 150 degrees hotter than HDPE. The coex nylon head won't be at the show, but a conventional Mueller head will be.

With other extrusion machines raising outputs, wheel blow molders haven't stood still either. Wilmington Machinery Inc., Wilmington, N.C., offers a new dual-parison wheel that "takes cavitation to a new high of 48 cavities," so it makes up to 17,000 bottles/hour, Wilmington says. The dual parison clamp section from the new machine will be displayed at NPE.

News in injection blow/stretch blow

Injection blow molding machines are also stretching for higher cavitation. In injection blow molding, Johnson Controls is introducing an IBM 122 model with 18 cavities, a configuration which hasn't been shown before, and one of the highest cavitations around. It will make HDPE pharmaceutical containers at the show.

At least two makers of single-stage stretch-blow molders will show novel processing flexibility at the show. Single-stage machines start with pellets, mold preforms, stretch and blow them, while two-stage machines start with preforms, then reheat, stretch and blow them. Nissei ASB Co. of Japan (with U.S. offices in Atlanta, Ga.) will show two stretch blow molding models, ASB 70 DPH and ASB 70 DPH-T (a multi-layer version). Both are flexible, small output

machines that were first seen at K '92, but haven't been shown in the U.S. Nissei says the DPH can make 15 million bottles/year in up to eight cavities and 10-11 million in six cavities.

Aoki Technical Laboratory in Japan (represented in the U.S. by Formex Inc., Dayton, Ohio) will stretch blow mold polyethylene terephthalate (PET) bottles using amorphous, or uncrystallized, PET without predrying, possibly the first this has been done at a show.

Pelletized APET is commercially available in some markets, but not in the U.S. In production, however, APET might be found in in-plant bottle regrind or post-consumer reclaim flake.

Normally this has to be recrystallized and dried before it can be added in bottle production because PET absorbs moisture (0.25%) from the air, which degrades the polymer and makes an unreliable container.

Instead of predrying the PET, Aoki modified the screw and barrel with venting to draw water out of the plastic as it's processed. Bottle grade PET resin starts at an intrinsic viscosity (i-v) of about 0.75; amorphous PET might have an i-v of about 0.65, strong enough for some bottle applications like salad oil or peanut butter, but not enough for thin-walled beverage containers with contents under pressure. So the challenge is to prevent any further i-v loss due to moisture left in processing.

New accumulator heads

One new accumulator-head machine at NPE will show closed-loop PLC (programmable logic controller) based controls. Wilmington will unveil a new closed-loop control system developed with Allen-Bradley PLC-based controls, a joint development. The new controls will be on a Model 120 (120 clamp tons) accumulator-head machine with a single 25-lb head. The system, completed in March, will be displayed for the first time at NPE. "Closed loop, PLC-based controls are just beginning to find their way into process monitoring," replacing dedicated microprocessor controls, notes Russell LaBelle, the president of Wilmington. Similar Siemens closed loop controls have also been used on Krupp and other accumulator head machines. Wilmington's program closes control loops around extruder RPM, 25 points of parison profiling, push-out ram speed in the head, barrel and head temperatures and pressures, and proportional hydraulic movements. The two clamp sections are independently controlled to accommodate moving sections in complex industrial blow molds.

Cincinnati Milacron in Batavia, Ohio, will show one of its new T-series Eclipse accumulator-head blow molders for the first time. The T 1100 has a single 35-lb "cyclone" head, which combines axial and radial flow to reduce knit lines in the finished part, Milacron says. A cutaway display of the head will simulate how plastic flows through two inlet channels and four spiral channels. Other accumulators heads have combined two flow directions before, but axial flow is more the norm, Milacron says. Several T-series machines have already been shipped into the market.

Higher outputs

Other new accumulator-head models will offer new features to raise output.

Battenfeld will run a Hartig model MR4-45(2)-20 7260 MCP with dual 20-lb heads, making trash containers at the show. A new air-surge tank maintains pressures of up to 150 psi in the grooved feed section of the extruder, "overcoming the pressure drop in the head as the shot is pushed out," Battenfeld says. Pressure control lets the machine achieve throughputs of up to 1,400 lb/hour, the company says. Battenfeld will also bring pictures of a new 100-lb accumulator-head Hartig, among the biggest built. (The biggest in the U.S., however, is still probably a massive, decades-old Battenfeld machine, making trash containers.)

Two other new blow molding machines, including one accumulator-head type, will be the first with new-generation Maco 6500 machine controls from Barber-Colman Co., Loves Park, Ill. The Sterling Division of Davis-Standard, Edison, N.J., will show its new SI-755D, the first accumulator head model with the new Maco controls. It has dual 5-lb heads and a new hydraulic clamp design. The clamp is supported on ways, not tie bars, and uses hydraulic cylinders on one side only, to act as tie rods. It will dry-cycle at the show.

Downstream handling developments

New automated downstream handling and testing equipment is featured at many booths because of its impact on production efficiency. Bekum, for example, will show automated takeout on a new BM-304D two-sided shuttle, which is the other machine at the show with the new Maco 6500 controls. The takeout uses water-cooled transfer pins.

A novelty in downstream testing is a new Plasma Leak Tester from Blow Moulding Controls Ltd. of the U.K. (with U.S. affiliate Blow Molding Controls Inc. in Glendale, Wis.), shown for the first time in the U.S. It debuted at the Birmingham show. The company says the plasma tester is as accurate as helium leak detectors for minute orifices and much faster. "We can find a 20-micron size hole in under a second in a 5-gallon container," says Thomas Bowers, general manager of the U.S. affiliate. The Plasma Leak Detector costs "roughly three times more than a pressure decay system," he says. Price is very fixture dependent. Fixtures to handle and hold the part can cost more than the plasma unit itself. The first production installation for automated testing of 5-gal containers is going into the U.K. now.

FGH will also introduce a line of dehumidification units from a new supplier, Fasti-Tepi. Fasti is a three-year-old Austrian maker of the dehumidifier, which controls mold sweating and improves cycle time. Tepi is their Milwaukee, Wis.,-based U.S. representative. The dehumidifier unit splits a stream of cold, dry air so that it is optimally directed inside of the bottle, according to bottle shape. As the air is vented, it's then reused to cool the top flash.

"It's less expensive and more effective than nitrogen cooling in improving cycle times," says Dieter Wunderlich, vice president of FGH.

HIGHLIGHTS

* First U.S. display of "long stroke" extrusion blow molding

* First U.S. display of 3-D, dual durometer coextrusion

* Stretch-blow molding of amorphous PET

* Stretch-blowing six different bottles at once

* New generations of PLC-based machine controls

* Quick mold change features

* Lots of downstream automation and testing

Sextuplets, and all different

Nissei will mold six different bottles at once on a small stretch-blow machine to show its flexibility

Nissei ASB (with U.S. offices in Atlanta, Ga.) will mold a different bottle shape in each of six cavities on its ASB 70DPH single-stage stretch-blow molding machine using a single preform design. The machine debuted at K '92, but this is its first U.S. appearance. The difference between that machine and the one that will be at NPE is in the preform conditioning rods, which cool preforms in different places for each bottle shape. The six-cavity array includes a triangular antacid-type bottle; wedge-shaped mouth wash bottle; baby oil bottle with shoulders; square steak sauce shape; long necked salade oil bottle and a plain round. On the baby oil bottle, for instance, the cooling core rod will "touch off" and cool the wide shoulders. Otherwise, if preform walls were all the same temperature when blown, the shoulders would stretch too thin and make a bad bottle. A three-layer coex ASB 70DPH-T machine will also make detergent bottles at the show in four cavities.

3-D and dual durometer too

Both 3-D manipulation of parisons and hard-soft-hard coextrusions have been demonstrated before, but not in the U.S.

Krupp will blow mold an unusual flashless automotive duct with soft and rigid sections of polypropylene (PP) and elastomer-modified PP on a KBS2-61 continuous extrusion industrial blow molder. Neither the robotically manipulated parison nor dual durometer coextrusion has been shown in the U.S. before, much less a combination of the two.

Patented head

The KBS2-61 has a patented new head with two-shot cylinders on top and internal push-out system, which the company says lies somewhere between continuous extrusion and reciprocating screw heads. The pushout system precisely controls the start and stop of the sequential coextrusion "within millimeters of machine settings," Krupp says. Model KBS2-61 has a new T-shaped open frame design with two extruders. The parison is guided into the tooling, which curves at both ends of the long part Clamping uses only one cylinder, not two, but still exerts 40 tons of pressure.

Enter the European long-strokes

They have wider platens, slower cycles, bigger extruders and much more

cavitation than standard shuttles

Long-stroke machine configuration is a quantum departure from a conventional one- or two-sided shuttle blow molder. A conventional shuttle machine has fast-moving arms with 1-6 cavities per platen. Shuttle arms make a fast swinging movement, generally no more than 1-2 feet to get parisons. A long stroke machine, however, may fill many times more cavities (up to 10-15) on one long pair of platens, which may travel over 4 ft. The movement may be linear in one plane and roughly twice as slow as a shuttle. And it closes with considerably higher clamping force. It also takes a larger extruder to fill the cavitation.

Battenfeld will feature long-stroke machines from both the Hesta line (made by R. Stahl Blasformtechnik GmbH in Germany, which Battenfeld represents worldwide), and from W. Mueller GmbH, a maker of extrusion blow molding machines, recently bought out by Battenfeld. Hesta's HLL 801 long-stroke machine will make one-liter bottles at the show in six cavities. The HLL 801 will also show a cooling mold station and oriented bottle takeoff to raise output and efficiency.

Battenfeld will show a 1/10-scale moving model of the Mueller long-stroke machine. Battenfeld makes its own long-stroke blow molder, but will promote Mueller's because of unique efficiencies like a quick set up using built-in ratchets, wrenches and other tools, so tool changes (not including heads) can be done in 10-15 minutes, Battenfeld says.

Krupp will also show a long-stroke machine at NPE with added features since it was first shown at K '92. Krupp's NPE model KBS1-10/1000 (1000 mm long stroke) will use an inclined blow pin to form neck spouts at an angle on 2.5-gallon HDPE containers. It will also show how wide platens mold bigger bottles as well as more bottles. It will run a two-cavity mold with 500 mm center distances. Krupp also has models with 750 and 1300 mm-long strokes, or a maximum linear movement of about 50 inches.

Techne Graham will show a Techne 6000 Twin long-stroke machine for the first time. At K '92, Techne showed a larger long-stroke Techne 10,000. The twin designation refers to mounting two molds side-by-side on one long platen. Techne's 6000 Twin makes anything from a 2-ounce to 2.5-gallon container in 2-10 cavities. At NPE it will make 32-ounce high density polyethylene handleware bottles. After the show, it will go to Metrolina Plastics in Shelby, N.C., to make gallon handleware for edible oil. It has a 90 mm extruder, brushless d-c drive motor, and 20-ton clamp.

GRAPHIC: Photograph

SIC: 3559 Special industry machinery, not elsewhere classified

IAC-NUMBER: IAC 16043084

IAC-CLASS: Trade & Industry

LOAD-DATE: August 28, 1995

Plastics World

July, 1990

SECTION: Vol. 48 ; No. 8 ; Pg. 38; ISSN: 0032-1273

LENGTH: 3001 words

HEADLINE: Blow molders discover the world has many shapes.

BYLINE: Miller, Bernie

BODY:
Blow molders discover the world has many shapes

Industrial blow molding has entered a new chapter beyond drums, picnic coolers, and tool boxes. Innovative designers and processors are pushing the blow molding process to new limits with engineering applications that are beginning to match structural foam for size and rigidity and challenge injection molding for sophistication in molded-in detail and integrated functions. Besides exotically shaped gas tanks, new opportunities abound for designing different types of enclosures based on the high strength-to-weight capabilities of dual-wall panels.

Automotive a prime mover

The automotive industry, the premier customer for industrial blow molding, is evolving into an even larger user of blow molded parts. Ducts, resonators, filter housings, and other air-handling components are now on their way to becoming as commonplace as washer and radiator-overflow bottles. Coming too are more brake-fluid reservoirs in nylon or nylon-polypropylene (PP) coextrusions and, with Europe in the lead, auxiliary radiator tanks in amorphous nylon or high-heat PP copolymer. These tanks are not overflow bottles, but are part of the pressurized cooling system and are used to make up for the radiator capacity lost to the lowered hood line.

In bumper systems, the 35 lb, mineral-filled PP fascia and fairings molded by Borse Industries, Willowbrook, Ill., for the Navistar 8300 and 9400 have helped put blow molding on the map with medium and heavy truck builders. Relatively low tooling costs give the process an edge in truck applications where 5,000-unit production is typical, a Borse executive says. And now passenger cars and light trucks can be considered better prospects because of the successful development of 5 mph polycarbonate-polyester alloy bumpers for the new Hyundai Sonata, blow molded by the ABC Group in Rexdale, Ont. ABC also is molding a PC-polyester bumper fascia for a 1990 Mack truck.

Fuel tanks, the biggest potential plum for blow molding, are finally starting to live up to their market potential. Blow molded tanks are installed

on more than 10% of the 14 million light trucks, vans, and cars produced last year. New passenger-car programs, including the Chrysler LH platforms and the Ford Escort and Tracer, are expected to drive the percentage close to 25% by 1993.

The prospects for blow molded tanks are buttressed by several generic factors, according to John E. Thorn, director, sales and marketing of the automotive division of Hedwin Corp., a Solvay America company, in W. Bloomfield, Mich. One trend to longer system warranties, possibly as long as 10 years, could be troublesome for steel tanks in high-salt areas. Other advantages are a 10-15% average weight saving, better resistance to various road hazards, and less than half the tool cost of fabricated steel.

"But the strongest driver for blow molding," Thorn says, "is shape flexibility. Car downsizing, reduced road clearance and now, the reemergence of the drive shaft with four-wheel drive, are leaving less and less space for the gas tank. Blow molded tanks can be sculpted to fit around obstructions and take advantage of all the space under the car. As a result, a plastic tank typically holds more fuel than the equivalent steel tank - and that extra capacity is considered a sales advantage," Thorn adds.

Hedwin's tank for the '89 Thunderbird and Cougar underscores Thorn's point (see photo, p. 38). Resembling an overheated guitar case, the tank narrows down from about 24 to 10 inches over its 4 ft length. It contains bulges and dips to fit the underbody, including a deep trough to straddle the driveshaft, that would be unthinkable in metal. Blow molded from Soltex K4606 high-density polyethylene (HDPE), the tank survives the traumatic test of a 20-ft drop at -40 degrees F while completely filled.

"The tank used the latest blow molding advances," notes project manager James Potter at Hedwin's South Bend, Ind. plant. A key technology was the Moog PWDS parison control system that solved the problem of balancing the wall thicknesses at areas with widely different stretch ratios, such as the driveshaft saddle and at the far edges of the tank (see story, p. 45).

Insert molding the fuel-pump reservoir and the mounting ring eliminated second operations. The project also required upgraded equipment with tight platen-parallelism control, stepped-up clamp pressure to handle the full permimeter pinch-off, and benefits from high platen-closing speeds.

Instrument panels next push

Beyond gas tanks, cross-car air ducts, and eventually instrument panels incorporating the ducts, are expected to be a major source of new business. About one-fifth of the current car production in Europe have ventilating systems in which at least some of the air conditioning, defroster and demister ducts are blow molded, mainly from PP copolymer. Typically these plastic components and flexible connecting tubes are hooked up on the assembly line.

A few cars, however, have moved to integrate these components into a single unit. The Peugeot 205, for example, consolidates seven separate pieces into a one-piece unit blow molded by STMP, a subsidiary of Solvay & Cie. One-piece ducts also are under development in the U.S.; the first production application is likely to be a heavy truck.

But the next design evolution - incorporating the cross-car air duct into a one-piece instrument panel - is being prototyped in several cooperative programs involving U.S. car builders, blow molders, and resin companies. In one of these pioneering programs, Hedwin has developed an integrated panel that consolidated five separate injection molded pieces and 12 metal brackets (see photo, p. 41). In addition to the air duct system, the prototype panel contains the mounting points for the instrument cluster and passenger-side air bag, wiring harness conduit, and a surface for trim pad.

To handle the under-windshield heat load, stresses from air-bag deployment, and ductile-failure requirements, the one-piece instrument panels will most likely be molded from engineering plastics, such as PC, modified polyphenylene oxide, or PC-ABS.

Besides assembly savings, Hedwin's Thorn points out that a two-thirds reduction in tooling lead time and an even greater saving in tooling costs further strengthen the case for blow molding over instrument panels assembled from multiple injection molded and stamped parts. "The process is the logical solution to just-in-time production and shorter product development cycles," Thorn adds.

An even more integrated design concept is being advanced by the ABC Group (see p. 39). The design engineers visualize blow molding the complete front end of the passenger compartment, including the instrument panel, and door modules, seats and center console, all with integral air ducts to improve air distribution throughout the passenger compartment. "We estimate the complete assembly can be made with 15-20 parts, which is just a fraction of the number currently needed," says ABC designer John Siraco.

More muscle for flat panels

Taking the cue from the blow molded load floor-seat backs, blow molding is now challenging structural foam and injection molding as a sheet metal replacement. Designers are turning to blow molded flat panels and covers for business machines, hospital furniture, and equipment enclosures.

For panels blow molding offers compeling benefits: light weight, material savings, two appearance surfaces, minimal finishing operations, and the ability to encapsulate inserts and other functional hardware. The development of internal reinforcing techniques - such as foam filling, tack-offs, and molded-in stiffners - has solved the problem of insufficient resistance to deflection.

"On a scale of 10, we are somewhere around 1 in capitalizing on the design potential of the process. There are tremendous opportunities for combining multiple parts and making lightweight structures," asserts David Bank, president of Papago Plastics, Inc., Rochester, N.Y. Inc., which specializes in blow-molding product and process development. "Designers need a lot more education on what can be done with blow molding," Bank states.

A pivotal application for blow molded panels is the $ 154,000 Xerox 5090 copier/finishing machine (see photo, right). Nine major exterior panels of this massive machine, including the 55 x 30 inch cover for the finisher unit, are blow molded by Modern Plastics Corp., Benton Harbon, Mich.

Other smaller panels are thin-wall structural foam or solid injection molding. All panels are molded from UL 5V grades of GE Plastics' Noryl styrene-modified polyphenylene oxide (PPO). One of the most sophisticated non-panel parts is the blow molded transition piece for the 5090's air-exhaust system (see inset). Tooled and molded by Papago Plastics, the one-piece adapter provides the transition between a square outlet and stepped series of duct diameters.

"Compared to solid and foam molding, the double-wall construction has a significantly higher strength-to-weight ratio," says John Sundquist, enclosures design manager for the 5090 and now an blow molding consultant in Rochester, N.Y.

"For example, the 55-inch panel, which measures 3/4 inch thick overall and has 0.080 inch walls (to satisfy VO requirements), weighs just 8 lb, including the internal rigid foam reinforcement. In 1/4-inch structural foam the panel would have weighed over 30 lb and it probably wouldn't have been as rigid. And in sheet metal it would have been impossibly heavy, Sundquist says.

Sundquist notes that the tooling costs for blow molded parts averages about one-third less than the tooling for equivalent molded parts and the lead time is also is about one-third lower. "We had our first blow molded parts in 12-14 weeks after we ordered the molds," Sundquist recalls.

Rigidizing techniques

Rigidity and thermal stability also were key requirements for the 5090's panels. Its top panels, for instance, must support a 200 lb load applied to a 6-inch square area with minimal deflection and no permanent set. This is equivalent to a well-fed workman standing on the cover with one foot.

The stiffness requirement was met by filling the molded panels with 2-lb density, closed-cell polyurethene foam at Papago Plastics. As side benefits, the foam core reduces both heat emission into the room (the machine is ducted) and noise transmission. Papago's Dave Bank notes that foam filling increases the stiffness of a hollow panel by up to tenfold, depending on panel dimensions, wall thickness, and type and density of the foam.

Tackoffs, another common approach to panel stiffening, also were used on the 5090. Tackoffs produce a dimpled second surface and lack the noise-suppression properties of a foam core, and provide about half to two-thirds the rigidity of foam-fill. Still, the strength is adequate for many applications and the technique has the cost advantage of being done as part of the molding process. Xerox used them in combination with a high modulus Noryl resin to stiffen the 3/8-inch thick back panels of the 5090 and, as a safety measure, to prevent the insertion of prying tools around their edges.

Designing a tacked-off panel remains a difficult problem because the strength is influenced by the size, spacing, and pattern of the tackoffs as well as by panel dimensions and direction of stress. Show-through of the contact points can occur without good coordination between wall-thickness design and molding conditions. While finite element programs are useful for stress calculations, no computer modeling programs exist that can directly arrive at an

optimum design for such panels.

Efforts to get some cost-performance benefits by combining foam fill and tackoffs can run into problems, specialists warn. Pressure from the expanding foam, particularly the closed-cell type, tends to force the unattached areas of the walls outwards. The resulting stress at the tackoff points can produce a slight, but noticeable sink mark or texture change on the exterior surface.

Encapsulated stiffeners

Another approach to rigidizing blow molded panels is the use of internal stiffening members which are encapsulated into the part during the molding process. Metal bars, tubes, or reinforced plastic profiles can serve as the reinforcements. One of the foamed top covers of the Xerox 5090, for example, contains an insert-molded 1/2-inch aluminum hex bar to maintain stiffness and flatness in the face of the heat generated by the copier's electrical components.

In large panels, weight can be saved by using tubing instead of solid rods. An example is the panels for a communications equipment cabinet molded by Modern Plastics Corp., some of them measuring as much as 6 ft long. "Standard electrical wiring conduit gives us the stiffness we need at much lower weight and less cost than bar stock or rods," notes Roger Duncombe, blow molding general manager.

Still another variation in stiffening members are pultruded beams. QPI Inc., an Essef Co. in Chardon, Ohio, insert-molds pultruded polyester I-beams in 60 X 24 inch storage shelves used in walk-in freezers. The high-density polyethylene shelves, weighing just 18 lb, are rated to support 1,200 lb. The HDPE shelves are lighter, less resonant, and easier to clean than metal shelves and, naturally, are non-rusting.

Unibody' construction

The potential to use blow molded panels as primary structural members has scarcely been tapped, blow molding designers contend. "Instead of hanging the panels on a metal frame, why not make the panels carry the load and eliminate the frame?" they ask.

In a pioneering example of this design concept, the entire structure of Simonton Industries' Innostation computer workstation is made up of 13 interlocking panels blow molded by Modern Plastics, Corp. (see PW, Feb. 1989, p. 31). Measuring about 24 inches square and 36 inches high, the workstation houses a personal computer and printer on blow-molded, roll-out shelves and supports a 70 lb monitor on the top panel (stiffened with molded-in metal tubing).

Besides cutting the shipping weight by 63 lb compared to the previous painted particle board construction, the blow molded Noryl modified PPO panels feature a no-hardware assembly concept. The unit is shipped in kit form and is assembled on site simply by mating molded-in tongues and grooves in adjacent panels.

A further application of interlocking structural panels is the all-plastic E-series of Oasis bottled-water dispensers, a redesign of an assembly made from

sheet-metal skins on a steel frame. The blow molded Lexan polycarbonate (PC) sides, 3/4 inch thick and weighing 3.5 lb, snap together by means of tongue and groove details to form the housing (see photo, p. 40). This simple assembly method makes it practical to ship the units in knockdown kit form. Tackoffs provide the rigidity to support a 200 lb top load without deflecting.

"Structural foam would have been heavier and would have required extra finishing," says David B. Chaney, president of Chaney Associates, Westerville, Ohio, whose industrial design firm designed the new E-series for Ebco Manufacturing Co.

"Injection molded panels probably would have called for a supporting edge frame and like, structural foam, would have required internal ribbing for stiffness, which raises the potential for show-through," Chaney continues. He adds that the smooth internal surface of the **blow molded** panels was a **definite** plus because it simplifies the job of cleaning the interior of the housing when rental units are reconditioned.

Internally colored PC eliminates painting and avoids problems from paint contamination when scrapped housings are reground for recycling. The molder is Reid Valve Co., Leetsdale, Pa.

Comparing tooling requirements, Chaney figures blow molding tooling costs about 20% less than injection or foam molds and were delivered 8-10 weeks sooner. "But," he emphasizes, "the real advantages of blow molding can come only if you design the parts with the process in mind. Converting designs that are predicated on the capabilities and limitations of some other process can waste a lot of blow molding's potential."

PHOTO : Spectacular Thunderbird gas tank, shown with M. Allen Maten, Jr., vice president and general manager of Hedwin Corp.'s automotive division, combines latest technology in parison programming, high strength Solvay HDPE resin, press performance, and insert molding.

PHOTO : Ultimate evolution for blow molding is suggested by concept for passenger car interior. Conceived by the ABC Group, Rexdale, Ont., the design integrates the instrument panel, doors, seating, console, and advanced air-distribution system for the entire passenger compartment.

PHOTO : Oasis bottled-water dispenser is built from self-supporting panels blow molded from internally colored polycarbonate, with molded-in tongue-and-groove fasteners that eliminate assembly hardware. Assembly savings, styling, and tooling economics were key benefits.

PHOTO : Xerox 5090 duplicating machine launched the use of big structural panels in business equipment. Largest of the nine exterior panels, all blow molded from modified polyphenylene oxide, is the 55-inch, foam-filled top cover, at the right end of the machine, that is rated to support the weight of a 200 lb workman. Exhaust-air duct for the Xerox copier demonstrates design sophistication, with transition from square mounting hole to series of stepped-diameter duct connectors. Innovative tooling design gathers parison material for deep-draw section at duct end.

PHOTO : Two stages of evolving car interior are displayed by Hedwin's John

Thorn. Dark unit is cross-car air duct that replaces multipiece assembly in Peugeot cars. Prototype instrument panel, which includes ducting, aims for still greater integration.

GRAPHIC: Photograph
SIC: 3089 Plastics products, not elsewhere classified

IAC-NUMBER: IAC 09206489

IAC-CLASS: Trade & Industry

LOAD-DATE: August 15, 1995

Materials Engineering

April, 1990

SECTION: Vol. 107 ; No. 4 ; Pg. 21; ISSN: 0025-5319

LENGTH: 2665 words

HEADLINE: Engineered blow molding: a hollow victory; plastics

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BODY:

Engineered Blow Molding: A Hollow Victory

Engineered blow modling combines the high performance properties of engineering resins with the design flexibility of double-wall construction and economics of blow molding.

Blow molding, the process of expanding a tube of hot plastic into a mold cavity, is primarily associated with containers and packaging. Commodity resins such as polyethylene, polypropylene, polyvinyl chloride, and polyethylene terepthalate dominate. Recently, however, new engineering resin formulations coupled with equipment advances have opened the door for higher performance plastics to exploit the benefits of blow molding.

Coined engineered blow molding (EBM), such materials as polycarbonate, modified polyphenylene oxide, nylon, acetal, polysulfone, polyphenylene sulfide, polyetherimide and thermoplastic elastomers are all in production or evaluation in a host of blow molded parts. From automotive bumpers and ducting to copy machine panels to hospital containers, EBM combines the high performance properties of engineering resins with the design flexibility of double-wall construction and economics of blow molding.

New Formulations

Until some five years ago, blow molding grades of engineering plastics were not readily available. Suppliers emphasized injection molding grades, where the goal was low melt viscosity and high flow to permit the plastic to travel through runner systems and fill complicated molds. The processing requirements of blow molding resins are virtually the opposite-strength and stretchability in the melt condition are essential.

In extrusion blow molding (the most common method used with engineering resins), a hollow tube of hot plastic, called a parison, is extruded between open halves of a mold. Hanging in midair, the parison is grasped at its sides and pinched off at its ends as the mold closes. Air is injected via a blow needle, expanding the parison into the mold cavity like an inflating balloon.

The plastic solidifies as it cools inside the mold.

Most engineering resins are inherently weak in the melt condition and are difficult to blow mold. To make them more suitable, manufacturers typically alter the chemistry or formulation of injection molding grades. Branching and crosslinking increase the molecular weight of the resins and create entanglement of polymer chains, both of which add to strength in the melt condition. Alloying with other plastics or adding rubber modifiers can also increase melt strength.

Low-Stress Processing

Compared to injection molding, blow molding is a low stress operation, requiring no more than 100 psi in the forming process. Blow molding produces parts with less molded-in stress than injection molding, so warpage and stress-related failures are reduced. In addition, molded-in inserts do not concentrate stress and are less likely to fail in service.

Molded-in details and sharp corner **definition** are limited with **blow molding**, and excellent surface finish can be difficult to obtain. Also, holes cannot be molded into blow molded parts and must be drilled or punched in secondary operations.

To accommodate blow molding of engineering resins, equipment modifications are typically required. Faster mold closing is needed to trap the parison before it has a chance to stretch. Higher temperatures are required in processing due to the high heat distortion temperatures of engineering resins. Higher clamp tonnages and steel tooling inserts may be needed to pinch off the tougher, faster-freezing EBM resins. Because of the low blow pressures involved, however, blow molding tooling can usually be made out of aluminum. These tools are less expensive and can be produced more quickly than the steel tooling used in the higher-pressure injection molding process.

Unlike most other molding processes, blow molding can be used to produce complex, double-walled parts in a single operation. Because of their inherent hollow, box beam construction, blow molded parts are strong and light-weight with the highest stiffness-to-weight ratio capability of any thermoplastic processing method.

Additional structure can be designed into blow molded parts using tack-offs, foam filling, or molded-in stiffners, ribs and corrugations. Tack-offs are compression welds between opposite sides of the parison, accomplished as the mold closes, tying opposite walls together. Added to an otherwise hollow panel, tack-offs increase load carrying ability in compression, bending and torsional modes by creating localized beam sections that transfer loads between the walls.

Get In Shape

EBM is an excellent process for producing parts which must absorb and dissipate mechanical energy, usually from impact. Their hollow nature allows parts to deform into themselves, while foam-filling can add an energy-absorbing core. The 1989 Hundai Sonata, for example, features a blow molded bumper beam covered with injection molded fascia. The beam absorbs impact up to 5 mph without damage and eliminates the need for the mechanical shock absorbing system previously used, saving 40 lb per vehicle. Xenoy 1402B, a polycarbonate/PBT

thermoplastic polyester alloy from GE Plastics, Pittsfield, MA, was selected for the beam because of its melt strength, toughness, and low temperature ductility. At -20 degrees F, this material exhibits notched Izod impact strength of 10 ft-lb/in. and gardner impact strength exceeding 400 in-lb. Parisons 8 ft long, weighing 7 to 7.5 lb were needed to blow mold the beam, which is 6 X 8 X 62 in. long.

The beam itself is not just a hollow tube, but is trilobed in cross-section as a result of two tack-offs running the entire length of the beam. It is mounted with the lobes facing the front of the car, like stacking three bicycle tires on top of each other. The tack-offs increase the overall stiffness of the beam, prevent collapse, and transfer load from the front section of the beam to the rear section, where it is mounted. To strengthen the rear of the beam, the mold is designed to produce a 2-to 3-fold increase in wall thickness at the rear of the beam compared to the front. This is accomplished by locating the parting line of the mold towards the back of the beam. When the mold closes and the parison is trapped along its sides, it has farther to stretch to fill the front part of the beam.

To determine the appropriate parting line location for the beam mold, GE Plastics used its proprietary Polymer Inflation Thinning Analysis (PITA) software. This finite element analysis program simulates the mold closing and inflation stages of blow molding and predicts material distribution within the part.

EBM is one of the most efficient and functional methods for producing structural flat panels. Stiffness-to-weight ratio of EBM panels exceeds that of fabricated hollow sheet-metal panels in many designs. Panels on the Xerox 5090 commercial color copying machine, for instance, are blow molded by Modern Plastics Corp., Benton Harbor, MI, from Noryl BN31 from GE Plastics. This modified polyphenylene oxide (PPO) has UL94 flammability ratings of VO/V5 depending on wall thickness, heat distortion temperature (HDT) of 180 degrees F, and notched Izod impact strength of 2.0 ft-lb/in. at --40 degrees F.

The top surface of the copier, a panel measuring 28 X 55 X 0.75 in., replaces up to six plastic or sheet metal parts and is blow molded flat within 0.040 in., end to end. The panel incorporates 30 bosses for self-tapping screws and a knock-out window for the paper feeding mechanism. To create the window, a large rectangular tack-off is made inside the panel which is then cut out in a secondary operation.

Blow molded panel systems can be designed to incorporate fastening points, mounting pads, slide rails and other functional elements. Integral hinge detail may be included, while interlocks are used to create snap-fit assemblies.

The naturally hollow construction of blow molded parts makes them especially suitable for vessels and containers, instrument panels, and ducting for air and wire management. Use of engineering resins provides the high-temperature performance required for under-the-hood applications, as well. The Ford Taurus incorporates a blow molded resonator in its air induction system. Zytel CFE 8005, a toughened nylon 6/6 from DuPont, Wilmington, DE, was selected for this application because of its ability to withstand hot spots of 300 degrees F and above. This material has an HDT of 428 degrees F at 66 psi, room temperature gardner impact strength exceeding 320 in.-lb, and resists attack of automotive

fluids. Zytel FN, a nylon/acrylic-rubber alloy, is suggested for flexible under-the-hood applications and has been blow molded into air ducting and fuel lines.

New Dimensions

Santoprene, a thermoplastic elastomer (TPE) with low compression set from Monsanto, St. Louis, MO, is used with polypropylene to form composite ductwork molded by MES Corp, Troy, MI. Blow molded in one piece, the ducts feature soft ends of TPE for clamping, and a rigid polypropylene body.

Blow molding of multiple resin ducting is made economically feasible by new equipment and a technique called multidimensional molding.

In this process the parison is dropped into a horizontal or tilting mold. Depending on the type of equipment used, either the extrusion head or the mold itself moves, so that the parison is snaked directly into the mold cavity. The lead end of the parison is pinched and filled with preblow air' to prevent it from collapsing.

This technique is especially suitable for S-or U-shaped ducting because it eliminates much of the flash. Using conventional techniques, a U-shaped duct, for instance, would require a parison wider than the U itself, so it could be caught on the sides by the mold. All the material in the center of the U shape would be flash. In addition, since the parison is not pinched by the sides of the mold, there is no side flash.

This technique is used with dual-resin ductwork because of the low level of waste. Although multiple-resin parisons can be extruded with conventional blow molding equipment, multi-resin flash cannot be reblended with either of the individual resins. This costly waste makes the conventional process too expensive.

In addition to multiple-resin molding with one resin following the other, the multidimensional machines can be programmed to extrude multi-layer resin parisons, as well. Most of this work is being done in Japan, where the multidimensional machines are manufactured and are much more prevalent.

Material Options

The increasing interest in blow molding has stimulated work by many suppliers to create suitable engineering resin formulations. In addition to Noryl, GE Plastics offers many blow molding grades of its engineering resins including Lexan polycarbonate for panels, Cycolac G series ABS resins for tanks, weather resistant Geloy acrylic-styrene-acrylonitrile (ASA) for exterior applications, and Ultem polyetherimide for chemical resistance and high temperature use.

Dow Chemical, Midland, MI offers Isoplast rigid thermoplastic polyurethanes to supplement its blow-molding grades of polystyrene, ABS, and Pulse brand ABS/PC blends. Though amorphous, the Isoplast polyurethanes exhibit the chemical resistance of crystalline resins and have good toughness and fatigue life over a wide range of temperatures. Suggested for automotive applications, they are available in clear, opaque, impact-modified and glass-reinforced grades.

A glass-filled polyphenylene sulfide, Ryton BR-95 from Phillips 66, Bartlesville, OK, is in evaluation for blow molded automotive manifolds and fuel rails. This material offers high flexural modulus, excellent chemical resistance and HDT of 500 degrees F. 20%-glass-filled nylon 6 formulations are offered by Montor Performance Plastics, Auburn Hills, MI, also suggested for automotive applications.

Blow molding grades of polysulfone are available from Amoco Performance Products, Ridgefield, CT. Udel CL2611 exhibits heat deflection temperature of 345 degrees F and withstands repeated steam sterilization at 270 degrees F. In addition to hospital baby bottles, this material is blow molded into containers used to hold body fluids removed during surgery, stomach pumpings, etc.

Originally formulated as injection-molding grades, the Triax 1000 series of nylon/ABS alloys from Monsanto offer the chemical resistance of nylon with good low-temperature properties. The Triax 2000 series of polycarbonate/ABS alloys offer notched Izod impact strength of 6 to 20 ft-lb/in. and are also said to be suitable for blow molding. Macroblend PC/ABS blends, available from Mobay, Pittsburgh, PA, offer improved chemical resistance compared to polycarbonates and are suggested for bumper beams.

Hoechst-Celanese, Chatham, NJ, is developing blow-molding grades of acetal, nylon, and thermoplastic elastomer with emphasis on large-part, extrusion blow molding. Thermoplastic polyolefins from Himont Corp, Wilmington, DE, provide molded-in color for Navistar International truck fascia and skirting.

Allied Signal Corp., Morristown, NJ, offers its Capron nylon and Dimension nylon/PPE blends for automotive applications such as hydraulic fluid and overflow antifreeze reservoirs. BASF Corp., Parsippany, NJ, is sampling Ultramid 94, a high viscosity, partially crosslinked nylon, and Arco Chemical Co., Newtown Square, PA, recently introduced Dylark DPN-520, a high viscosity SMA/PBT blend.

PHOTO : Blow molding allows economical production of large, complex parts. Engineering resins

PHOTO : provide increased heat distortion temperature, flame retardancy and impact strength while

PHOTO : double-wall construction affords high stiffness-to-weight ratios.

PHOTO : The excellent impact energy management characteristics of hollow, blow molded parts are

PHOTO : put to good use in automotive bumper beams. Shifting the mold parting line towards the

PHOTO : rear of the bumper causes an increase in wall thickness in that area. Impact is absorbed

PHOTO : in the thinner front section and the load transferred to the rear where the beam is

Plastics World

May, 1993

SECTION: Vol. 51 ; No. 5 ; Pg. 28; ISSN: 0032-1273

LENGTH: 2002 words

HEADLINE: How two **pros** solve **molding** woes; **injection molding**

BYLINE: Kirkland, Carl

BODY:

Molding troubleshooters at Dow Plastics say most likely something in the process causes the problem, not the material

"All of my customers can mold and mold very successfully. When we get called, everything already has been tried two or three times." M.F. (Mike) Martin is development leader of the Core Technology Team (CTT) at Dow Plastics, The Dow Chemical Co., Midland, Mich. He admits that after molders try everything two or three times most tend to zero-in on an easy target as the root cause of their problems--the resin. Yet, Martin says, while the resin is never ruled out, it is usually the culprit less than 1% of the time.

Most of the time, Martin and his other CTT teammates find the root cause of most problems lies in improper process optimization. "For some reason, the process is not frequently thought of as the reason for the failure," he says.

Rod Weirauch, injection molding supervisor for CTT, explains that the Team was formed as a part of Dow Plastics and Dow's TS&D group about 18 months ago to address the injection molding process itself, to focus on new developments in the process and to help Dow's customers solve complex problems. The 25-member team concentrates on injection molding, extrusion and thermoforming, part and polymer testing, pigments and colorants and, to a lesser degree, blow molding.

When trouble calls

Some problems occur that cannot be solved by a long-distance phone call, Martin says, and they demand a plane ticket to ride. He knows he has to make a house call when he hears the following from his customers:

* Your (Dow's) resin messed up the job

* Scrap rates are suddenly too high for profits

* "Something" has changed since the last resin shipment

* The molding window is too narrow

* We can't maintain SPC

* The job has become too costly (cycle times are greater than what the job was bid at)

* Your competitor's material works/worked better

* The part's surface appearance is unacceptable

* Our scrap is significant, but it occurs inconsistently and is random

* Part properties are unacceptable

* There is a painting or plating problem with the molded part

* And, there is an assembly or durability problem with the final component

Again, Weirauch and Martin say they rarely are called until molders check things over once or twice and are unable to find the root cause of the problem. The material is blamed. "I really look forward to the time when our resin causes the problem," Martin jokes. "In my experience, only one or two times was it a resin problem."

Weirauch continues: "Invariably, it is something in their process that has changed. Something overlooked. It is something not intuitively obvious to a molder. We at Dow have the luxury of not having to mold parts for a living. A lot of times we can see problems from a different perspective, so we often can be more objective in our analysis."

Martin and Weirauch agree that the following are their most frequently cited causes for molding troubles:

* A colorant or mixing problem

* A check valve performance problem

* A screw design performance problem

* Poor machine conditions (mechanical or controller problems)

* Errant machine controller tuning. (Tuning constants should change from one material to another, they note.)

* Insufficient drying. ("May to September is what we call 'splay season,'" Weirauch jokes.)

* A resin problem

* Improper mold design.

* Improper machine set-up. (Both agree that every generic type of material is different--what works for ABS won't work for polycarbonate.

Frequent set-up problems

Martin and Weirauch agree on the top three set-up problems they've encountered in the field. Use of melt decompression (suck back) leads the list. "Try not to use it," Martin says. "It can cause splay, burning and bubbles."

Martin cautions molders to make sure the molding machine is giving you what you ask for. "Don't use a set point of 0.1 just because that is what you've always used. It is a machine by machine, tool by tool type of thing. Start out low and increase. If the machine gives you what you ask for, you probably have proper melt decompression, but if it really exceeds the setpoint, the machine has a control problem. Molders are rarely aware of this." He recommends trying profiled backpressure and screw rpm control to eliminate drool instead.

The number two machine set-up problem is mismatched or worn equipment. If the nozzle/screw diameter or if the screw/check valve seat diameter are mismatched or worn, burning can result. "There are a lot of different vendors for check valves, but there is no standard design for the rascal," says Martin, explaining the mismatch problem.

Regarding burning, he says most molders know that a worn check valve will cause short shots, "But they can have a lot of dead areas that cause material hang-up." Weirauch added that Dow has just completed an evaluation of check valves and is developing check valve recommendations for each of its moldable material types.

The last of the top three set-up problems is caused by inexperienced operators. "It is not a training problem, but an awareness issue," Martin says. "All plastics are not processed the same and every machine has a personality of its own. Catch yourself when you're about to say 'We've always done it that way.'"

Martin and Weirauch have three suggestions for what molders should do if they run into complex problems. Martin calls these suggestions his "pontifications." First, he says, "Don't hesitate to call your vendor for help. Do it as soon as the problem occurs. It is orders of magnitude more difficult to solve a problem when emotions are high and that machine has been molding scrap for weeks. It is much easier to provide help over the phone, early on, than on the shop floor."

Material suppliers can bring unique experience, ample process research capabilities and specialized tools to the problem-solving table. "I do for a living what most of my customers hope they never have to do again," Martin says. "By solving problems in many molding environments with all Dow plastics on a weekly basis, I probably have seen the problem before or will see it again."

Also, Dow owns more than 20 machines of various types and capabilities with clamp tonnages from 28 to 3,250 tons. They are equipped to simulate and correct most problems. And when it comes to specialized tools, Dow has quite an arsenal, including personal computer-based data acquisition devices. These devices allow Dow's troubleshooters to design a problem-solving experiment, collect the machine's responses, tune the machine and get hard-copy records of the successful process.

Second, Martin says "Standardize!" Know what equipment is being used, use the

same type of hardware for each job TABULAR DATA OMITTED and establish a standard process for all jobs by machine at the sampling."

And, third, Martin advises that molders use statistical process control. "Use a standard process, change that process only in response to a measured response and keep a log of all changes and the reasons they were made."

Most demanded plastic producing machinery and equipment by

end-user and supplier country during 1989

(Thousands of US $)

	US
Injection machines for one mold	2171
Other injection machines	1448
Injection machines over 5kgs	4113
Extrusion machines single spindle type for thermoplastics or granulated elastomers	2756
Other extrusion	3806
Blow molding machines	3390
Vacuum machines	1816
Granulating machines, mills and crushers	708
Mixers or mixing mills	1606
Parts for plastic working machinery	4112
Total	25,926

Source: Mexican Secretariat of Commerce and Industrial

Development - Mexican Import/Export Statistics

Types of plastics processing

Type of process	Number of companies in

	Mexico
Injection	1050
Extrusion	900
Blow molding	450
Laminating	180
Rotary molding	105
Foaming	90
Compressing	60
Thermoforming	45
Other transforming	120
Manufacturers of equipment	20
Manufacturers of peripheral equipment	50
Manufacturers of plastic molds	50

Source: "The Plastic Production Machinery and Equipment Market in Mexico," American Embassy, March 1990.

Resins total supply (1991)

Resins	Prod. (Tons)	Imports (Tons)	Supply (Tons)
LDPE	337,200	33,600	370,800
HDPE	212,800	112,300	325,100
Polypropylene (PP)	36,100	146,800	182,900
Polystyrene (PS)	137,700	22,000	159,700
ABS	16,600	4,600	21,200
PVC	335,800	14,800	350,600

Polyacetal (POM)	1,600	400	2,000
Bottle grade PET	17,645	214	17,858
Acrylic (PMMA)	11,000	767	11,767
Nylon (PA)	4,900	800	5,700
Polycarbonate (PC)	0	1,174	1,174
Polyurethane (PUR)	47,900	1,400	49,300
Total	1,159,245	338,854	1,498,099

Total resins supplied to the Mexican market remains relatively small--about 5% of the U.S. total.

Source: Phillip Townsend Associates Inc.

GRAPHIC: Photograph; Chart; Table

SIC: 2820 Plastics Materials and Synthetics ; 3089 Plastics products, not elsewhere classified

IAC-NUMBER: IAC 14176561

IAC-CLASS: Trade & Industry

LOAD-DATE: August 25, 1995

L2: Entry 1 of 2 File: EPAB Sep 25, 1996

PUB-NO: EP000733462A1
DOCUMENT-IDENTIFIER: EP 733462 A1
TITLE: Method for making double-walled container

PUBN-DATE: September 25, 1996

INVENTOR-INFORMATION:

NAME	COUNTRY
DAVID, GEORGES	FR
TIRADON, MICHEL	FR

ASSIGNEE-INFORMATION:

NAME	COUNTRY
GEORGES DAVID ETS	FR

APPL-NO: EP96420081
APPL-DATE: March 14, 1996

PRIORITY-DATA: FR09503527A (March 21, 1995)

INT-CL (IPC): B29 C 65/66; A01 G 27/02; B65 D 8/06; B29 C 59/00
EUR-CL (EPC): A01G027/02; B65D011/16, B29C065/66

ABSTRACT:

CHG DATE=19990617 STATUS=O> The container, esp. a flower pot with a reserve of water,consists of an inner pot (2) made from a rigid injection-moulded material, and a blow-moulded outer shell (3), both e.g. of plastic. The pot and shell are assembled while still hot so that shrinkage of the material fixes them together. The base (2b) of the inner pot has a hollow central projection (2f) surrounded by a vertical ring (2i) and its upper edge has a rim (2d) which turns outwards and has a groove (2e). The outer shell has an inward-facing collar (3d) round its rim to engage with the groove. The outer wall of the pot has a series of vertical ribs (2m), and its base projection is perforated to allow water to pass through.

L Number	Hits	Search Text	DB	Time stamp
1	316	(47/$ or 220/$ or 264/$ or 206/$).ccls. and ((rim or lip) with vertical with (fin or flange or protrusion))	USPAT; US-PGPUB	2003/02/12 08:16
2	2	(47/$ or 220/$ or 264/$ or 206/$).ccls. and ((rim or lip) with (zigzag or (zig near2 zag) or (z near2 (shape or shaped))) with (fin or flange or protrusion))	USPAT; US-PGPUB	2003/02/12 08:19
3	0	(47/$ or 220/$ or 264/$ or 206/$).ccls. and ((rim or lip) with (zigzag or (zig near2 zag) or (z near2 (shape or shaped))) with (fin or flange or protrusion))	EPO; JPO	2003/02/12 08:20
4	0	(47/$ or 220/$ or 264/$ or 206/$).ccls. and ((rim or lip) and (zigzag or (zig near2 zag) or (z near2 (shape or shaped))) and (fin or flange or protrusion))	EPO; JPO	2003/02/12 08:19
5	9	(47/$ or 220/$ or 264/$ or 206/$).ccls. and ((rim or lip) with (zigzag or (zig near2 zag) or (z near2 (shape or shaped))) with (fin or flange or protrusion))	USOCR	2003/02/12 08:41
6	0	(47/$ or 220/$ or 264/$ or 206/$).ccls. and ((rim or lip) with (zigzag or (zig near2 zag) or (z near2 (shape or shaped))) with (fin or flange or protrusion))	DERWENT	2003/02/12 08:41
7	42	(297/$ or 264/$).ccls. and (injection with (mould or mold or molding or moulding) with chair)	USPAT; US-PGPUB	2003/02/12 08:45

L Number	Hits	Search Text	DB	Time stamp
1	1194	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (mineral or calcium or carbonate))	USPAT; US-PGPUB	2003/02/12 10:10
2	44	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (mineral or calcium or carbonate) same injection)	USPAT; US-PGPUB	2003/02/12 10:13
3	4	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (mineral or calcium or carbonate) same injection same (rapid or quick or rapidly or quickly or accelerate))	USPAT; US-PGPUB	2003/02/12 10:16
4	39	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (mineral or calcium or carbonate) same injection same (rapid or quick or rapidly or quickly or accelerate))	USOCR	2003/02/12 10:17
5	40	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (mineral or calcium or carbonate) same injection same (rapid or quick or rapidly or quickly or accelerate or accelerated))	USOCR	2003/02/12 10:18
6	29	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (calcium or carbonate) same injection same (rapid or quick or rapidly or quickly or accelerate or accelerated))	USOCR	2003/02/12 10:19
7	0	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (calcium or carbonate) same injection same (rapid or quick or rapidly or quickly or accelerate or accelerated))	USPAT; US-PGPUB	2003/02/12 10:19

L Number	Hits	Search Text	DB	Time stamp
1	1194	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (mineral or calcium or carbonate))	USPAT; US-PGPUB	2003/02/12 10:10
2	44	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (mineral or calcium or carbonate) same injection)	USPAT; US-PGPUB	2003/02/12 10:13
3	4	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (mineral or calcium or carbonate) same injection same (rapid or quick or rapidly or quickly or accelerate))	USPAT; US-PGPUB	2003/02/12 10:16
4	39	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (mineral or calcium or carbonate) same injection same (rapid or quick or rapidly or quickly or accelerate))	USOCR	2003/02/12 10:17
5	40	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (mineral or calcium or carbonate) same injection same (rapid or quick or rapidly or quickly or accelerate or accelerated))	USOCR	2003/02/12 10:18
6	29	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (calcium or carbonate) same injection same (rapid or quick or rapidly or quickly or accelerate or accelerated))	USOCR	2003/02/12 10:19
7	0	(264/$ or 220/$ or 206/$).ccls. and ((cool or cooling or cooled) same (calcium or carbonate) same injection same (rapid or quick or rapidly or quickly or accelerate or accelerated))	USPAT; US-PGPUB	2003/02/12 10:20
8	24253	(264/$ or 220/$ or 206/$).ccls. and ((calcium or carbonate) same filler injection)	USPAT; US-PGPUB	2003/02/12 10:20
9	48	(264/$ or 220/$ or 206/$).ccls. and ((calcium or carbonate) same filler same injection)	USPAT; US-PGPUB	2003/02/12 10:27
10	5	(264/$ or 220/$ or 206/$).ccls. and ((calcium or carbonate) same filler same injection same (cool or cooling or cooled))	USPAT; US-PGPUB	2003/02/12 10:31
11	3	((calcium or carbonate) same filler same injection same (cool or cooling or cooled))	EPO; JPO	2003/02/12 10:32
12	1	((calcium or carbonate) same filler same injection same (cool or cooling or cooled))	DERWENT	2003/02/12 10:32